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Appendix A: The Feasibility of Mitigating Kepone Contamination in the James River Basin

Battelle Memorial Inst, Richland, WA. Pacific Northwest Labs.

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The Feasibility of Mitigating Kepone Contamination in the James River Basin

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This report is Appendix A of the EPA report "Mitigation Feasibility for the Kepone-contaminated Hopewell/James River Areas". The work reported in this appendix was conducted by Battelle Memorial Institute's Pacific Northwest Laboratory for the EPA Kepone Mitigation Feasibility Project. It discusses the Kepone problem, the properties of Kepone, current Kepone distribution in the Hopewell area, the movement of Kepone in the James River and some of the ecological effects of Kepone. The report provides an ecological profile of the James River and a limited evaluation of some mitigation approaches for the Hopewell area and the James River. The report includes much of the field sampling data and preliminary reviews of certain mitigation techniques, excluding dredging.

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THE FEASIBILITY OF MITIGATING KEPONE CONTAMINATION IN THE JAMES RIVER BASIN

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While conclusions and recommendations are included in each participant's report, they are conditional within the scope of each project participant's tasks. Project conclusions and recommendations are the responsibility of EPA and are included in the Kepone Mitigation Feasibility Project Report.

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CHAPTER I

EXECUTIVE SUMMARY

During the period 1966-1975, a highly chlorinated organic pesticide, Kepone, was discharged to the environment around Hopewell, Virginia from production activities at the Allied Chemical Semi-Works Plant and the Life Science Products Company plant. It is estimated that more than 91,000 kg (200,000 lb) of Kepone may have been released. Oyster and sediment samples from as early as 1967, and fish and bird samples from the early 1970's contain Kepone quantities indicating that measurable losses can be attributed to Allied Chemical's processes. Life Science Products releases were associated with atmospheric emissions, wastewater discharges and bulk disposal of off-specification batches.

Atmospheric emissions associated with Life Science Products drying and bagging operations resulted in widespread transport of Kepone dusts in Hopewell and as far as 25 km (16 mi) north. The Kepone subsequently settled to the surface soils where in Hopewell it is estimated that as much as 45 to 450 kg (100 to 1000 lb) currently reside within a radius of 3 km (2 mi) from the Life Science Products plant site.

Life Science Products wastewater discharges entered the sewer system and reached Bailey Creek after passage through the Hopewell primary treatment plant. In turn, these waters flowed to Bailey Bay, in the James River on its way to Chesapeake Bay. It is estimated that 540 kg (1200 lb) of Kepone presently lie in Bailey Bay attached to sediments. Another 9,000 kg (20,000 lb) are bound in the top foot of sediments of the James River.

Bulk discharges other than those released to the sewer occurred at two known sites and perhaps more. Batches of incompletely reacted raw materials or off-specification product were hauled to the Hopewell landfill and a disposal trench at the former Pebbled Ammonium Nitrate Plant where they were dumped. Kepone-bearing residues from the Life Science Products plant closure are also buried at the landfill, and Kepone-contaminated sludge from the Hopewell treatment plant is stored in a specially constructed disposal lagoon nearby.

An extensive sampling plan was implemented by Battelle in the Hopewell and Bailey Bay areas to document current Kepone levels and determine the routes of transport. Samples were collected from sediments, surface and deep soils, surface and ground water, sewage, and the sewer system. Results of analyses were evaluated to determine the most probable means of Kepone entry into the James River. A summary of estimated environmental inventories of Kepone is presented in Table I.1.

Current studies have shown that Kepone migrates into the James River as a result of runoff and leachate which solubilizes soil deposits of Kepone and suspends contaminated particulate matter. The estimate of this input varies from a low of a few grams per day during dry weather to as much as 64 g (0.14 lb) per day during storms.

TABLE I.1. ESTIMATE OF KEPONE RESIDUALS

Residing In	Estimated Quantity of Kepone	
	kg	lb
Sewer System	23	50
Surface Soil (1 in.)	45-450	100-1,000
Kepone Sludge Lagoon	100	220
Bailey Bay Sediments*	540-2,000	1,200-4,300
James River Sediments*	9,000-17,000	20,000-38,000
Drums at Hopewell	9,400	20,700
Drums at Portsmouth	13,000	28,800
Landfill†	1,400	3,100
Pebbled Ammonium Nitrate Plant Site	100	220
Rounded total*	33,700-43,600	73,500-95,500

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* Low value reflects estimate extrapolated from mean concentrations, high value reflects estimates based on mean plus one standard deviation.

† Includes identified deposits only.

A mathematical model was constructed for the James River to predict the movement of Kepone. The model includes use of a sediment transport code which was first successfully employed and verified on the Columbia and Clinch Rivers. Input data were obtained from sampling of the James River during the project. Verification was accomplished using data from surveys conducted by the Virginia Institute of Marine Science. Based on outputs from the model and estimates of the water/sediment partition coefficient, it is projected that Kepone deposits in Bailey Bay and the James River are being moved seaward by natural dispersive mechanisms at a rate of approximately 76 to 170 kg/yr (167 to 374 lb/yr) past Burwell Bay (River Kilometer 28). Over 65% of these losses or 56 to 110 kg/yr (109 to 243 lb/yr) is due to the desorption of Kepone from sediments and subsequent transport in a dissolved state. An additional 10 to 100 kg/yr (22 to 220 lb/yr) of Kepone are carried out of the river in the flesh of migratory fish.

The presence of Kepone in the James River has contributed to adverse environmental and economical impacts. Laboratory data reveal that Kepone is acutely toxic to fish at concentrations as low as 6.6 μg/ℓ (ppb). Chronic exposure to as little as 0.05 μg/ℓ (ppb) Kepone may lead to sublethal effects. While specific cause-and-effect relations cannot be documented in the James River, an occurrence of scoliosis in finfish and declining populations of sensitive species coincides closely with the Kepone production at Hopewell. A major impact, which can be identified, is the presence of Kepone in blue crabs and commercial fish at levels in excess of FDA Action Levels. This has resulted in emergency orders by the State of Virginia restricting sport and commercial fishing in the James River and its tributaries. These restrictions impacted the sport and commercial fisheries of the James River as well as fishery-related activities.

At the projected rate for movement of Kepone down the James River, these environmental and economical effects are likely to continue. Laboratory data suggest that aquatic life may not be safe from adverse effects until Kepone levels can be reduced to 0.008 μg/ℓ (ppb) in water and 0.015 μg/g (ppm) in sediments and in food for biota. It may take decades for the James River to reach these levels through natural conditions. Kepone discharges from the James River are believed to be too small to threaten similar effects in Chesapeake Bay. The 76 to 170 kg/yr (167 to 374 lb/yr) of Kepone, which passes from Burwell Bay, will be sorbed to clean sediments. These Kepone-laden sediments will ultimately enter Chesapeake Bay, but the inflow rate is small and much may pass out of the Bay prior to deposition on the bottom. However, caution is necessary because no hydrodynamic data have been reviewed in the Bay area to quantify projections. nor is the possible impact of unusual storm events known. Further effort is needed to clearly define risks to Chesapeake Bay.

There are few technological approaches available which could accelerate the restoration of the Kepone-contaminated James River. Sediments can be dredged, but overboard disposal of spoils might aggravate the Kepone problem. Hence, sediments will have to be contained or fixed. In situ stabilization may be attractive if an effective fixation agent can be identified. Two novel approaches were also found to have some promise after preliminary laboratory evaluation: (1) application of activated carbon to bottom sediments in situ to decrease availability of Kepone to the water column and food chain; and (2) use of retrievable sorbents in situ to physically concentrate and remove Kepone. Institution of any of these options would cost in excess of $3 billion. Even if restoration were aimed only at sediments containing the bulk of the Kepone [93% lie in sediments with 0.1 to 1.0 μg/g (ppm)] the cost would exceed $1.5 billion.

The findings of the Battelle study are presented in Chapter II. These are followed by a discussion of the sequence of events leading to the EPA Kepone Mitigation Feasibility Project in Chapter III. Subsequent chapters address the methods employed and results obtained in each of seven study areas: (1) the physical, chemical, and biological properties of Kepone related to fate and movement in the environment (Chapter IV); (2) the status of environmental Kepone residues in the Hopewell area (Chapter V); (3) the ecological make up of the James River (Chapter VI); (4) the status of Kepone residues in the James River and predictions of movement based on mathematical modeling (Chapter VII); (5) the ecological effects of Kepone (Chapter VIII); (6) the evaluation of alternatives available for mitigation of Kepone in the Hopewell area (Chapter IX); and (7) the evaluation of nondredging alternatives for mitigation of Kepone in the James River (Chapter X). Each chapter begins with a brief summary of its contents and the major findings therein. Detailed support data for chapters can be found in referenced appendices.

CHAPTER II

STUDY FINDINGS

The Battelle effort is one of four funded studies of EPA's Kepone Mitigation Feasibility Project. Some of the key objectives of the project were to assist in answering a series of questions pertaining to Kepone contamination in the James River:

- What is the current distribution of Kepone residuals in the environment?
- How are these deposits changing with time?
- What impacts can be associated with the current and projected future inventories of environmental Kepone contamination?
- What actions can be taken to decrease those impacts?
- What costs are associated with potential restoration alternatives?

Ultimately, the answers to these questions will provide a foundation for answering the overriding or summary issue of what should be done about the present situation. An in-depth discussion of study methods and results is presented in this report both in the form of information reported by others and as results of research initiated as a part of the EPA Kepone Mitigation Feasibility Project. In order to facilitate the application of the data in this report to future restoration efforts in the James River Basin, the pertinent findings of the study are summarized in this chapter.

CHAPTER III - PROBLEM STATEMENT

- Kepone production output from Allied's Semi-Works Plant in Hopewell totaled 763,475 kg (1,681,865 lb) from 1966 through early 1974.
- Little data exist concerning the discharge of Kepone residuals into the environment from Allied's production facilities.
- Eleven oysters collected in 1967 from the James River near its mouth contained an average of 0.1 μg/g (ppm) Kepone in their tissues.
- Sediment samples from the Jamestown/Dancing Point reach of the James River had levels of Kepone of 0.04 and 0.02 μg/g (ppm) in 1967.
- Of four bald eagle carcasses collected between 1970 and 1973 in eastern Virginia, three had Kepone in their livers at concentrations of 12, 86, and 0.13 μg/g (ppm) wet weight.

- Four bluefish taken from the lower James River in 1973 were subsequently analyzed and contained 0.94, 0.01, 0.56, and 0.96 μg/g (ppm) Kepone in their edible meat.

- Life Science Products Company (LSP) began producing Kepone in March 1974 with a total recorded output of 769,390 kg (1,696,225 lb) over its one-and-a-half years of operation.

- Kepone was discharged from the LSP plant in: (1) atmospheric releases from drying and bagging operations; (2) daily wastewater effluent; (3) acute wastewater discharges due to spills, malfunctions, and bad batches; and (4) solid waste loads routed to terrestrial sites.

- Analysis of LSP wastewater effluent showed levels of Kepone ranging up to 36,600 μg/ℓ (ppb) during the production period.

- Discharge of contaminated wastewater from LSP occurred at the Hopewell landfill, at the site of the former Allied Pebbled Ammonium Nitrate Plant, and into the city sewer system.

- Sludge from the Hopewell Primary Sewage Treatment Plant analyzed in 1975 contained from 200 to 600 μg/g (ppm) Kepone.

- In 1975, Kepone was detected in surface waters at concentrations of 0.3 μg/ℓ (ppb) in the James River near Hopewell, 0.1 μg/ℓ (ppb) in the Appomattox River, and from 1 to 4 μg/ℓ (ppb) in Bailey Creek.

- Soil from the LSP site contained more than 10,000 μg/g (ppm) Kepone immediately following plant closure, with levels diminishing to 2 μg/g (ppm) 900 m (3,000 ft) away.

- Sampling in the James River in 1976 showed Kepone levels in the bottom sediment extending from City Point at Hopewell to Newport News in the lower tidal zone. Concentrations ranged from 0.02 to 1.0 μg/g (ppm) in the top 9 cm of sediment, with the exception of Bailey Bay where levels up to 10 μg/g (ppm) were reported.

CHAPTER IV - PROPERTIES OF KEPONE

- Kepone is strongly sorbed onto soil and sediment particles such that at equilibrium in the environment, concentrations on particulate matter are 10^4 to 10^5 times those in the surrounding water.

- Laboratory and field observations indicate that Kepone does not volatilize to any significant extent.

- Kepone's solubility is a direct function of solution pH. Kepone levels in leachate from sediments with 1 μg/g (ppm) Kepone increased from 0.031 μg/ℓ (ppb) at a pH of 7.2 to 6.84 μg/ℓ (ppb) at pH 12.0.

- Algae from the James River have been found to contain Kepone concentrations above the level required to adversely affect productivity (0.35 to 1.0 μg/g).

- Kepone was bioconcentrated by laboratory oysters, mysids, and spot from sea water containing less than 0.03 μg/ℓ (ppb) Kepone.

- Bird species in which Kepone residuals have been detected include the great blue herron, mallard duck, coot, black duck, wood duck, herring gull, Canadian goose, hooded mersanger, and bald eagle.

- Experiments indicate that plants sorb Kepone in their roots but do not transport it upward through the stem and leaf compartments.

- There is no evidence to date of Kepone degradation in the natural environment.

CHAPTER V - ANALYSIS OF CURRENT KEPONE DISTRIBUTION

- Use of a toulene:ethyl acetate solvent system for Kepone analysis eliminates extract cleanup steps for the majority of Hopewell environmental samples.

- An estimated 540 kg (1200 lb) of Kepone reside in the sediments underlying Bailey Bay and Bailey Creek.

- The most heavily contaminated bottom sediments of Bailey Bay display a vertical Kepone distribution, with concentrations peaking at depths of 10 to 20 cm.

- Highest Kepone levels in Bailey Bay occur at the mouth of Bailey Creek, with elevated levels continuing in conjunction with the flow pattern of creek water through the Bay.

- Surface soil samples from Hopewell contain Kepone concentrations ranging from several hundred μg/g (ppm) in the area adjacent to the former Life Science Products (LSP) plant site to 0.1 μg/g (ppm) in the outskirts of town.

- Sampling results show little downward movement of Kepone through the soil column, with concentrations in the top 2.5 cm (1-in.) layer generally a full order of magnitude (10-fold) greater than Kepone levels in the second 2.5 cm (inch) of soil.

- The current inventory of Kepone in Hopewell soils resulting from atmospheric fallout during production periods totals between 45 and 450 kg (100 and 1000 lb).

- Surface runoff translocates an estimated 60 to 70 g/day of Kepone from Hopewell soils to the James River system during average periods of rainfall.

- Highest levels of Kepone in surface runoff were detected in the vicinity of the LSP site, ranging from 10 to 700 μg/ℓ (ppb).

- No Kepone was detected in shallow ground-water samples from three wells in the LSP neighborhood.

- Detectable levels of Kepone were found in shallow ground-water wells at the Hopewell landfill, at the site of the Kepone/sludge disposal lagoon, and at a location east of the Hopewell sewage treatment plant. Measured concentrations of Kepone at these wells were 0.24, 0.81, and 0.08 μg/ℓ, (ppb), respectively.

- Over a 5-month sampling period, two ground-water seeps from the bank below the Kepone/sludge disposal lagoon contained between 9.6 and 361 μg/ℓ (ppb) Kepone.

- The concentration of Kepone in the Hopewell domestic water supply system is below a detectable limit of 0.02 μg/ℓ (ppb).

- The highest Kepone concentration in an environmental sample, 35,163 μg/g (ppm), was found in marsh sediment adjacent to the southeastern portion of the Hopewell landfill.

- Kepone levels in the top 10 cm (4 in.) of this marsh average 12,200 μg/g (ppm) and account for approximately 1,400 kg (3100 lb) of the chemical in a 1000 m^2 (0.25 acre) area.

- Analysis of samples from the Pebbled Ammonium Nitrate Plant site identified Kepone residuals to depths of 12 m (40 ft), comprising an estimated inventory of 100 kg (220 lb) of Kepone.

- An average of 6 g/day of Kepone exit the Hopewell primary sewage treatment plant (STP) in its effluent.

- Continuing Kepone levels in the plant effluent are fed by storm runoff originating in the Life Science neighborhood, by supernatant drawoff from the STP holding tank, and by inflows from the residential sanitary sewer lines.

- The amount of Kepone residuals persisting in the Hopewell sewer system and STP is estimated to be less than 23 kg (50 lb).

- Approximately 100 kg (220 lb) of Kepone are present in the Kepone/sludge disposal lagoon.

- An estimated 9000 kg (20,000 lb) of Kepone reside in the top foot of sediment underlying the James River.

CHAPTER VI - ECOLOGICAL PROFILE OF THE JAMES RIVER

- James River species and their distribution through the tidal portion of the river are summarized in Appendices D and K.
- The Virginia Institute of Marine Science estimates total summer biomass of finfish in the James River (RM 0-45) to be 1.65×10^6 kg (3.4×10^6 lb).

CHAPTER VII - THE MOVEMENT OF KEPONE IN THE JAMES RIVER

- Particulate Kepone concentrations up to 0.241 μg/g (ppm) Kepone were found in the river proper. Suspended matter in Bailey Creek contained up to 1.38 μg/g (ppm) Kepone.
- Dissolved Kepone concentrations up to 0.042 μg/ℓ (ppb) were found in the river proper. At most stations, dissolved Kepone was below the detectable limit of 0.006 μg/ℓ (ppb).
- Only two mathematical models are currently available for calculating migration of contaminants by taking into account both dissolved and particulate species and their interactions.
- Mathematical simulation of Kepone transport under most probable flow conditions yields an estimate of 89.1 kg/yr Kepone transported seaward from Burwell Bay.
- In the most probable scenario, Kepone transport is comprised of 75% dissolved material and 25% associated with particulate material.
- Calibration and verification activities reveal good agreement with all available data.
- Sensitivity analysis under the most probable flow conditions with Kepone river bed values twice as high and a 5-fold increase in partition coefficient (5×10^{-4} in place of 1×10^{-4}) yield a prediction of 170 kg/yr transported seaward of Burwell Bay.
- In the latter case, dissolved Kepone accounts for 92% of the total load.
- Analysis of conditions likely to result from implementation of cleanup in selected segments of the river suggests that little or no effect will be noted in total Kepone discharge levels. Ambient Kepone concentrations can be reduced in treated areas, however.

CHAPTER VIII - ECOLOGICAL EFFECTS OF KEPONE

- The fish species in the James River that is most sensitive to the acute toxic effects of Kepone is spot (Leiostomus Xanthurus) with a 96-hr LC_{50} of 6.6 μg/ℓ (ppb).
- Sublethal effects with chronic exposure have been reported at Kepone concentrations in water as low as 0.05 μg/ℓ (ppb) (sheepshead minnows).
- Kepone bioconcentration factors calculated from laboratory studies range from 8.1 in blue crab to a high of 13,470 in mysid.
- The major route of Kepone uptake in fish is from Kepone dissolved or suspended in the water.
- Filter feeding shellfish take up Kepone from contaminated suspended solids.
- Bioaccumulation of Kepone from food and sediments is significant in blue crabs and polychaete worms.
- In laboratory studies, contaminated oysters depurated Kepone to non-detectable levels in 7 to 20 days.
- Fish species both bioconcentrate and depurate Kepone at slower rates than oysters.
- Analysis of field and laboratory data suggest that Kepone levels at or below 0.008 μg/ℓ (ppb) in water and 0.015 μg/g (ppm) in bottom sediment would result in no adverse ecological impacts.
- The current FDA Action Limits are 0.3 μg/g (ppm) Kepone in the edible meat of fish and shellfish, and 0.4 μg/g (ppm) in blue crab.

CHAPTER IX - HOPEWELL ALTERNATIVES EVALUATION

- Current data on human and ecological dose response to Kepone levels in soil are insufficient to establish technical criteria for designating required clean-up actions in Hopewell.
- Potential techniques for mitigating the impacts of Kepone in surface soil include scraping or excavation, soil cover and seeding, lime treatment to accelerate leaching, amine accelerated photolysis, and the addition of synthetic soil amendments.
- Uncertainties concerning the effectiveness and environmental impact of lime treatment deem it an inadvisable mitigation alternative at this point.

- Tree cover inhibits the effectiveness of amine accelerated photolysis and synthetic soil amendments.

- Cost of excavating and drumming contaminated marsh sediment adjacent to the southeastern portion of the landfill is estimated to be $5000.

- Covering Nitrogen Park with 5 cm (2 in.) of uncontaminated soil and reseeding would cost approximately $3,500.

- High-temperature incineration is an effective means of destroying harmful Kepone residuals.

CHAPTER X - ALTERNATIVES FOR THE MITIGATION OF KEPONE IN THE JAMES RIVER

- In laboratory studies, two stabilization agents (molten sulfur and an organic epoxy grout) offered up to 1 order of magnitude reduction in Kepone leachate levels.

- Silicate-based stabilization agents available at the time of testing were found to be ineffective in reducing Kepone leachate concentration.

- Should silicate-based fixative be found that is effective, in situ application may warrant testing.

- Application of activated carbon to contaminated sediments decreases the availability of Kepone to the surrounding aquatic system.

- In laboratory studies, coal did not significantly inhibit Kepone transfer from contaminated sediment to the overlying water.

- Retrievable sorbents are capable of removing Kepone from contaminated sediments.

- Polymer film laid over the sediments in Bailey Bay is an insufficient mitigative action since perforation necessary to allow venting of degradation gases will also allow the escape of Kepone.

- Activated carbon and UV-ozone treatment are each effective in removing Kepone from certain aqueous solutions.

- Application of the laboratory tested options to the contaminated portions of the James River would cost in excess of $3 billion.

- Unit costs for mitigation alternatives in the James River were estimated to be:

    - Application of Retrievable Carbon - \$0.52/ft^3 sediment
    - Application of Retrievable Sorbent in situ - \$0.90/ft^3 sediment
    - Oozer Dredge with Ocean Disposal - \$1.07/ft^3 sediment
    - Oozer Dredge with Sulfur Stabilization - \$1.37/ft^3 sediment
    - Oozer Dredge with Incineration - 1.57/ft^3 sediment

CHAPTER III - PROBLEM STATEMENT

SUMMARY

Content

Chapter III provides a description of the Kepone contamination issue prior to initiation of the EPA Kepone Mitigation Feasibility Study. Following a brief background statement, a section on Kepone production is presented. This includes a description of the chemical processes utilized by Allied and Life Sciences, and a table of annual production output. Next, a chronology of significant events relating to Kepone contamination is summarized. This is followed by a discussion of Kepone residual discharges, including avenues of release, approximate amounts discharged, and the resulting deposition in the environment following cessation of production.

Findings

- Kepone production output from Allied's Semi-Works Plant in Hopewell totaled 763,475 kg (1,681,865 lb) from 1966 through early 1974.

- Little data exist concerning the discharge of Kepone residuals into the environment from Allied's Production facilities.

- Eleven oysters collected in 1967 from the James River near its mouth contained an average of 0.1 μg/g (ppm) Kepone in their tissues.

- Sediment samples from the Jamestown/Dancing Point reach of the James River had levels of Kepone of 0.04 and 0.02 μg/g (ppm) in 1967.

- Of four bald eagle carcasses collected between 1970 and 1973 in eastern Virginia, three had Kepone in their livers at concentrations of 12, 86, and 0.13 μg/g (ppm) wet weight.

- Four bluefish taken from the lower James River in 1973 were subsequently analyzed and contained 0.94, 0.01, 0.56, and 0.96 μg/g (ppm) Kepone in their edible meat.

- Life Science Products Company (LSP) began producing Kepone in March 1974 with a total recorded output of 769,390 kg (1,696,225 lb) over its one-and-a-half years of operation.

- Kepone was discharged from the LSP plant in: 1) atmospheric releases from drying and bagging operations, 2) daily wastewater effluent, 3) acute wastewater discharges due to spills, malfunctions, and bad batches, and 4) solid waste loads routed to terrestrial sites.

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- Sludge from the Hopewell Primary Sewage Treatment Plant analyzed in 1975 contained from 200 to 600 μg/g (ppm) Kepone.

- In 1975, Kepone was detected in surface waters at concentrations of 0.3 μg/ℓ (ppb) in the James River near Hopewell, 0.1 μg/ℓ (ppb) in the Appomattox River, and from 1 to 4 μg/ℓ (ppb) in Bailey Creek.

- Soil from the LSP site contained more than 10,000 μg/g (ppm) Kepone immediately following plant closure, with levels diminishing to 2 μg/g (ppm) 900 m (3000 ft) away.

- Sampling in the James River in 1976 showed Kepone levels in the bottom sediment extending from City Point at Hopewell to Newport News in the lower tidal zone. Concentrations ranged from 0.02 to 1.0 μg/g (ppm) in the top 9 cm of sediment, with the exception of Bailey Bay where levels up to 10 μg/g (ppm) were reported.

INTRODUCTION

Kepone is a registered trade name for decachlorooctahydro-1,3,4-methano-2H-cyclobuta(cd)pentalen-2-one, a member of the cyclodiene family of insecticides. It was developed by Allied Chemical Company in the early 1950s to control specific insect pests. The majority of production was exported to Central America for use on the banana root borer and to a European firm for conversion to other products. Domestic use was limited to small quantities placed in ant and roach traps at a maximum allowable level of 0.125% Kepone. Such traps were marketed by 27 firms in the U.S.

Kepone has been a subject of public concern since health officials found high concentrations in the blood of a Life Science Products Company chemical worker in July 1975. Subsequent investigations revealed contamination of the local environment originating from atmospheric, wastewater, and bulk releases of Kepone from production facilities in Hopewell, Virginia. As a result of this contamination, the Life Science Products Company was closed. Numerous law suits have been filed against the company, the staff, and Allied Chemical who supplied the raw materials and paid a tolling fee for production of the products. One suit filed by the Federal government resulted in the largest fine ever levied under Public Law 92-500. Finally, some 118 km (75 mi) of the James River have been closed to the commercial and recreational taking of certain fish, shellfish and crab species. Most recently, the ban on male blue crabs was extended to southern portions of Chesapeake Bay near the river's mouth.

The tidal James River, extending from below the city of Richmond to its mouth in the lower Chesapeake Bay, supports the livelihood of many watermen and individuals associated with fishery-related activities. Thus, the restrictions stemming from Kepone residuals are believed to have had an adverse effect upon the economy of the region. It has been projected that no significant amount of Kepone will reach Chesapeake Bay, but little definitive work has been directed to substantiate this. The major economic impact of such an event and the potential closure of Chesapeake Bay waters to commercial and recreational fishing make a detailed investigation of paramount concern now, while time may allow appropriate preventive actions for the future.

The work performed by Battelle and reported in this document has been directed toward determining: (1) the magnitude of previous releases of Kepone; (2) the distribution of available Kepone; (3) the existence of any substantial current sources of Kepone for movement into the James River; (4) the fate and effects of Kepone deposits in the James River; and (5) the nature and efficacy of potential mitigative activities. The final objective is important in that it will influence the selection of any remedial actions taken to cleanse the river of Kepone. However, if all objectives are to be achieved, an understanding of the overall Kepone problem is necessary.

PRODUCTION OF KEPONE IN HOPEWELL, VIRGINIA

Location

The city of Hopewell lies along the southern shore of the James River, 118 km (75 mi) from Chesapeake Bay (Figures III.1-III.3). The economic core of this city of approximately 25,000 people is a major industrial chemicals complex. Kepone production in Hopewell began in 1966 and continued through the summer of 1975. The pesticide was manufactured at two locations: the Allied Chemical Company Semi-Works plant located near Gravelly Run and the Life Science Products Company plant on State Highway 10 to the west of the Allied Plant (Figures III.4 and III.5). Production at the two facilities occurred at different times, at different intensities, and in somewhat different modes. In the following sections the processes used to produce Kepone are discussed.

Production Process at Allied

The Allied Chemical Corporation Semi-Works plant was designed to be a flexible facility for the production of specialty or smaller volume products on a batch basis. It was used for Kepone production intermittently during the period 1966-1974. Kepone was made there by reacting hexachlorocyclopentadiene (HCP) with sulfur trioxide (SO_3), sodium hydroxide (NaOH) and sulfuric acid (H_2SO_4) in the presence of a catalyst, antimony pentachloride ($SbCl_5$). The empirical equation for this reaction is:

$$\underset{\text{(HCP)}}{2C_5Cl_6} + 2SO_3 + 8NaOH + H_2SO_4 \rightarrow \underset{\text{(Kepone)}}{C_{10}Cl_{10}O} + 2NaCl + 3Na_2SO_4 + 5H_2O$$

In the 1966 Allied process (Ameen, 1966), each batch consisted of charging a 2800-ℓ (750-gal) glass-lined reactor with 3443 kg (7590 lb) of HCP, 11.3 kg (25 lb) of antimony pentachloride ($SbCl_5$) catalyst and 0.68 kg (1.5 lb) of water. The reactor was heated to 60°C with agitation. Over a time period of 5.5 hr, 1513 kg (3336 lb) of sulfur trioxide (SO_3) (50% excess) were added at a rate which maintained reactor temperature at 60 to 65°C. The entire mixture was finally heated to 85 to 90°C, at a pressure of 3500 g/cm^2 (50 psig) or below for 10 to 12 hr.

The resultant mixture was quenched in 6% aqueous sodium hydroxide (NaOH) solution to hydrolyze the reaction mass and put it in solution. Twenty-three separate quenches were required for each reaction batch because of the large quantity of caustic solution that was used. In the quenching process, each of two 2800-ℓ (750-gal) vessels was charged with an average of 1800 ℓ (475 gal) of water and 159 ℓ (42 gal) of 50% NaOH, followed by 217 kg (479 lb) of reaction mass. This mixture was then heated, while agitating, to 95 to 100°C. Additional NaOH was added if the mixture failed to go into solution.

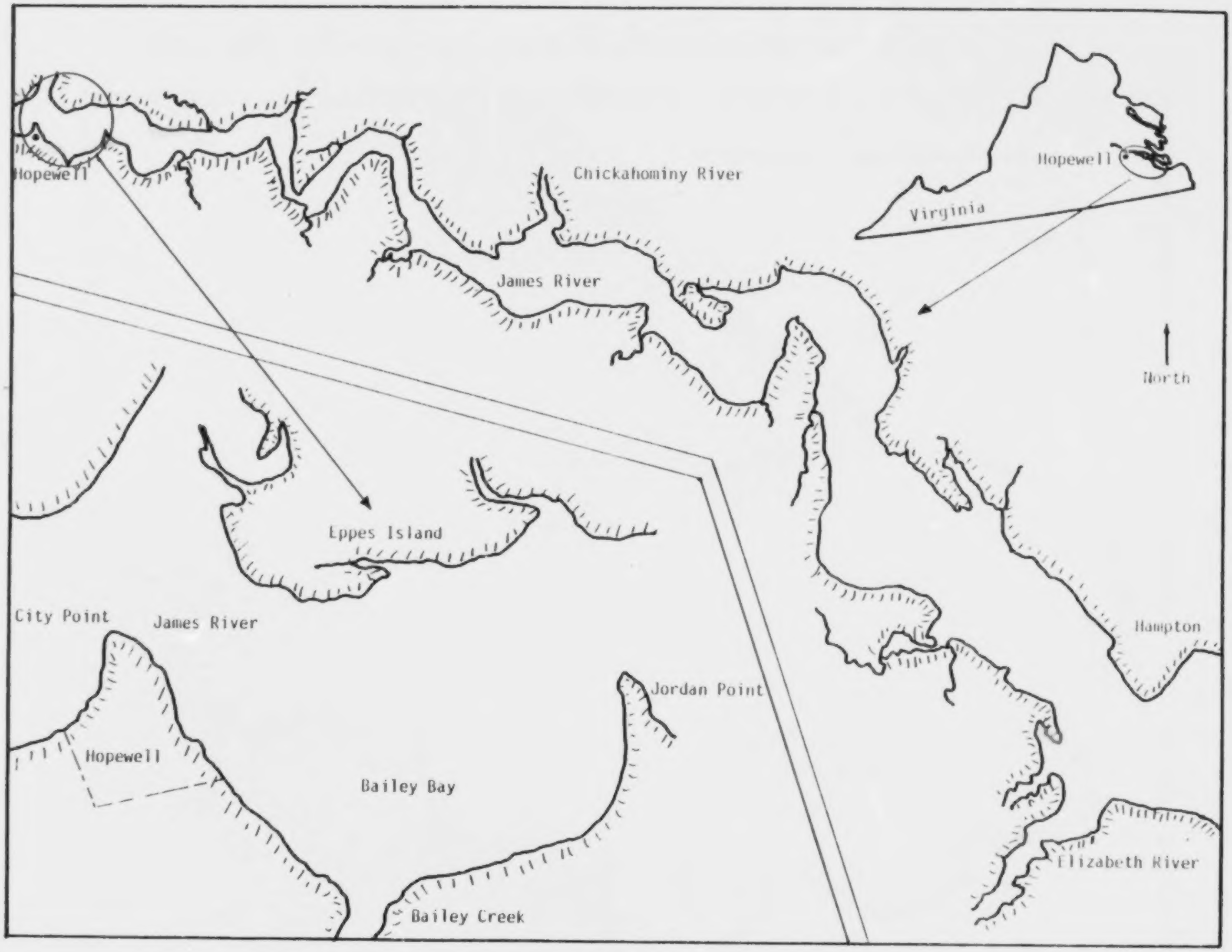
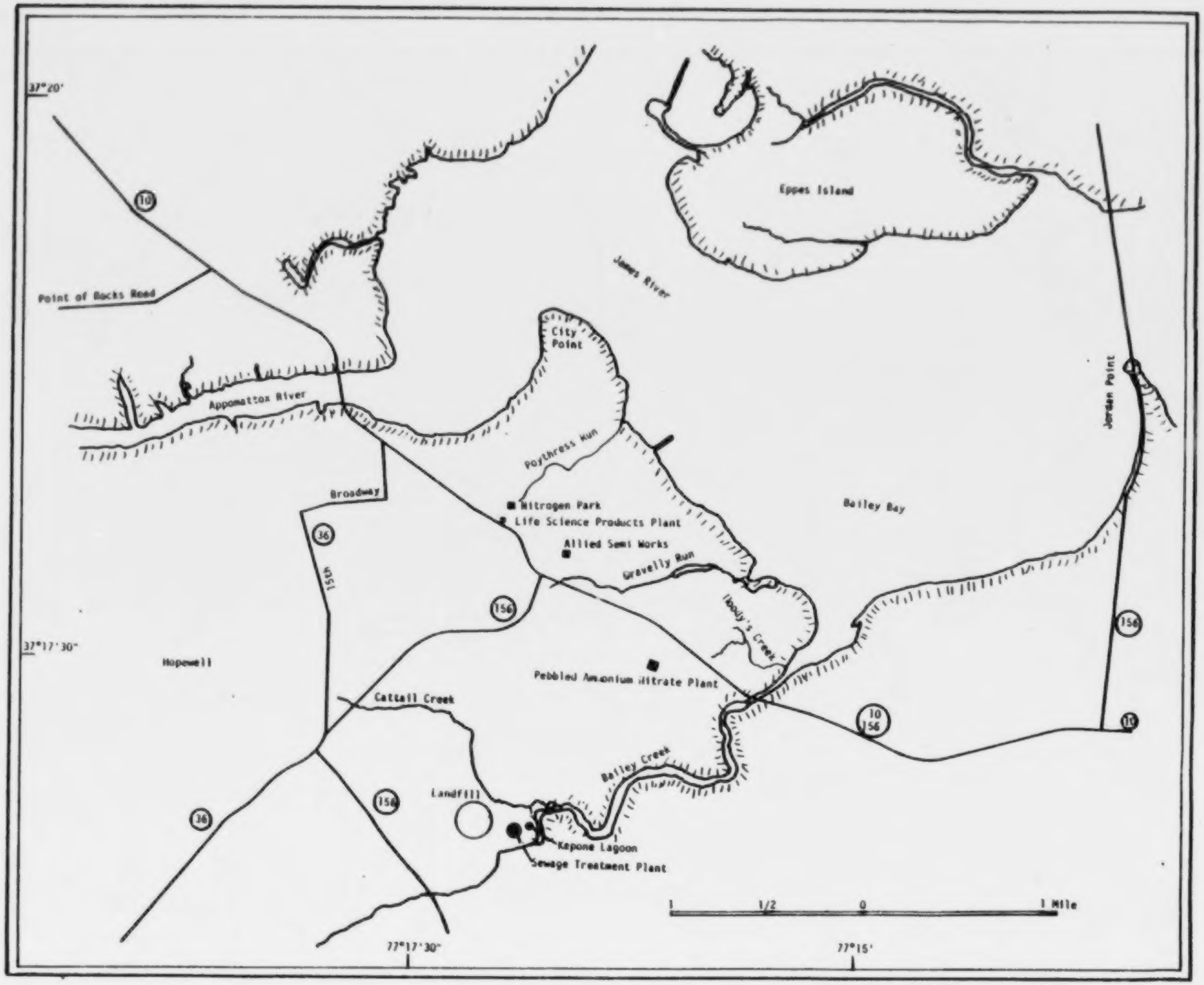

Hopewell
Chickahominy River
Hopewell
Virginia
James River
North
Eppes Island
City Point
James River
Hampton
Jordan Point
Hopewell
Bailey Bay
Elizabeth River
Bailey Creek

FIGURE III.1. Location of the Affected Areas on the James River



37°20'
10
Point of Rocks Road
Appomattox River
James River
Eppes Island
City Point
Poythress Run
Broadway
36
15th
Nitrogen Park
Life Science Products Plant
Allied Semi Works
Gravelly Run
Bailey Bay
Jordan Point
156
Moody's Creek
37°17'30"
Hopewell
Pebbled Ammonium Nitrate Plant
Cattail Creek
10
156
10
Bailey Creek
Landfill
Kepone Lagoon
Sewage Treatment Plant
1
1/2
0
1 Mile
77°17'30"
77°15'

FIGURE III.2. Relative Position of Important Features in the Hopewell Area

Reproduced from best available copy.

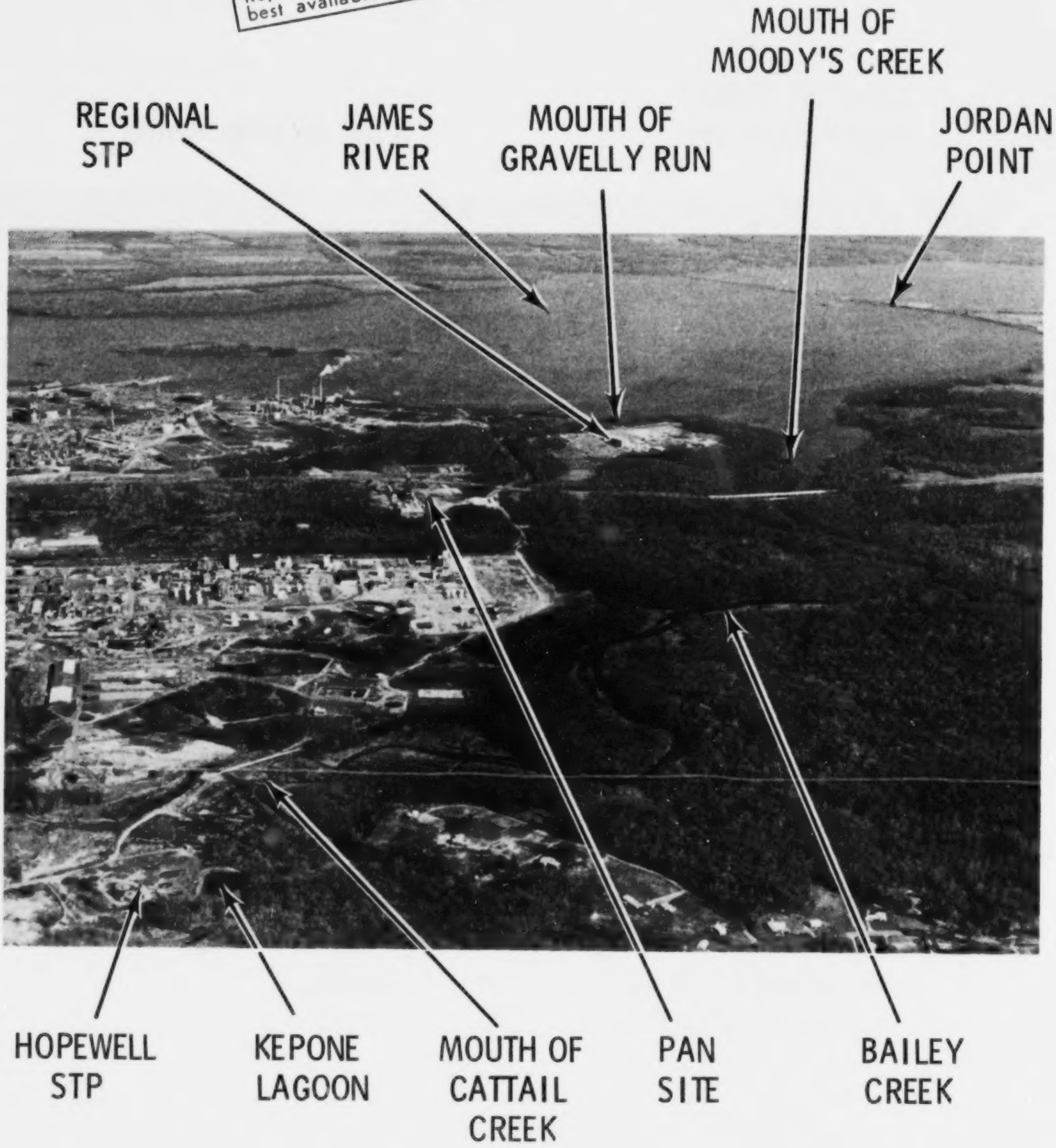

REGIONAL STP
JAMES RIVER
MOUTH OF GRAVELLY RUN
MOUTH OF MOODY'S CREEK
JORDAN POINT
HOPEWELL STP
KEPONE LAGOON
MOUTH OF CATTAIL CREEK
PAN SITE
BAILEY CREEK

FIGURE III.3. The Bailey Creek Area

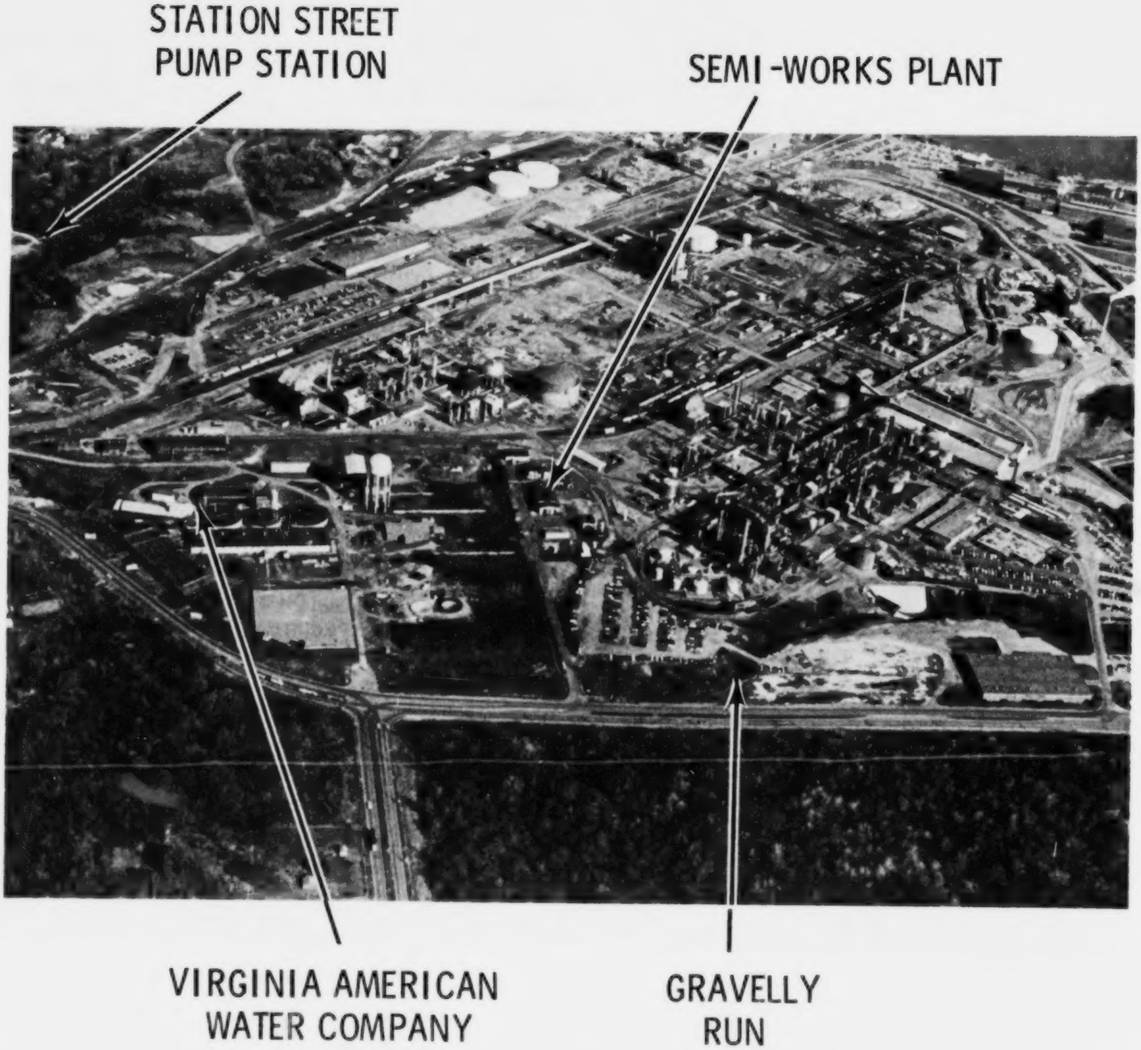

STATION STREET PUMP STATION
SEMI-WORKS PLANT
VIRGINIA AMERICAN WATER COMPANY
GRAVELLY RUN

FIGURE III.4. The Allied Semi-Works Plant Site and Surrounding Area

Reproduced from best available copy.

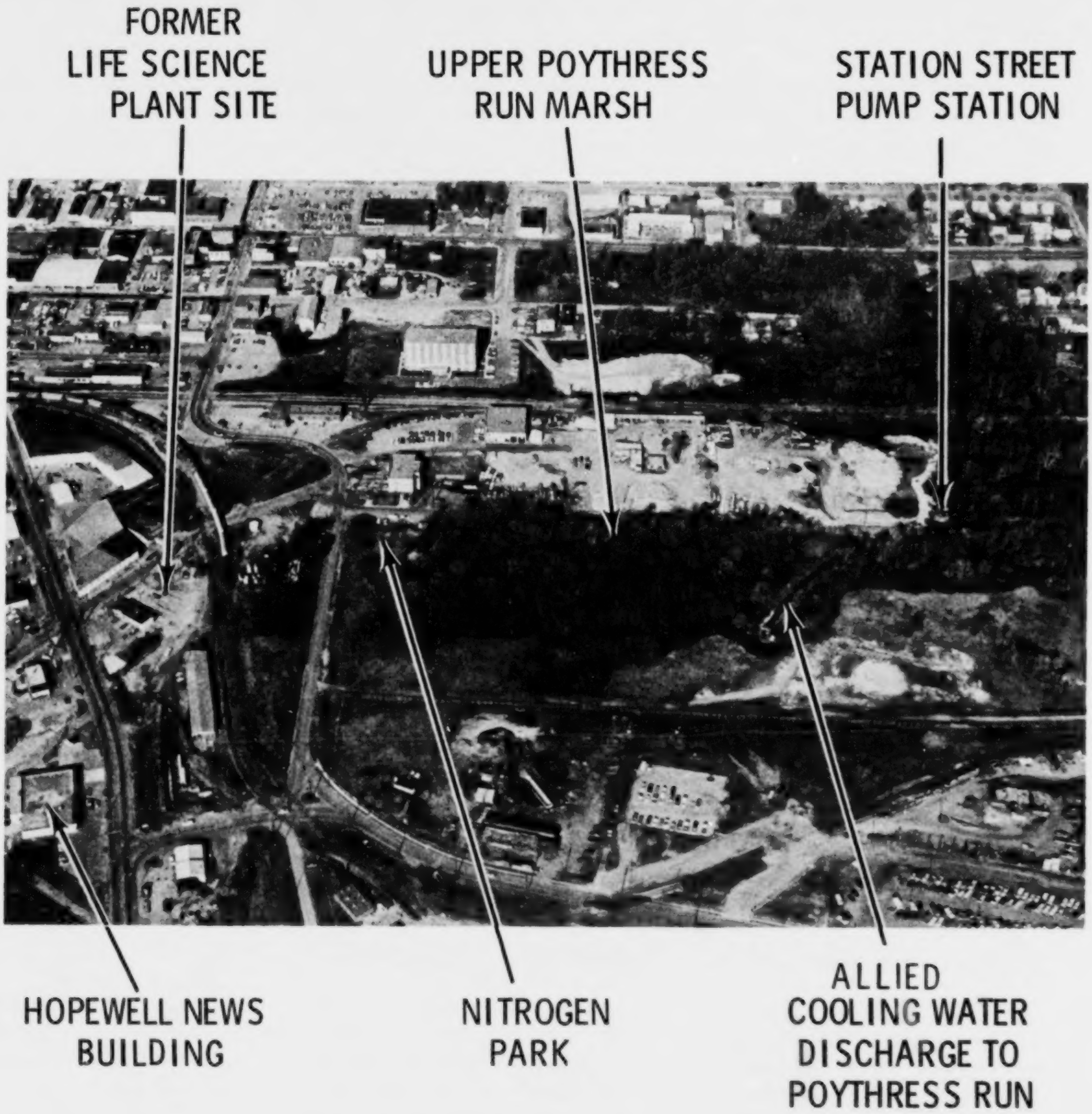

FORMER LIFE SCIENCE PLANT SITE
UPPER POYTHRESS RUN MARSH
STATION STREET PUMP STATION
HOPEWELL NEWS BUILDING
NITROGEN PARK
ALLIED COOLING WATER DISCHARGE TO POYTHRESS RUN

FIGURE III.5. The Life Science Products Plant Site and Surrounding Area

The solution was then neutralized at 95 to 100°C with about 23 kg (50 lb) of sulfuric acid (H_2SO_4) to a pH of 5 or 6 to precipitate the Kepone. The slurry was transferred to a 2800-ℓ (750-gal) centrifuge feed vessel and cooled to 60°C.

The Kepone was recovered by centrifuging the slurry in a 122-cm (48-in.) diameter by 76-cm (30-in.) high centrifuge. The centrifuge was charged with about 181 kg (400 lb) wet cake per load, each cake being washed with 300 to 380 ℓ (80 to 100 gal) of warm water to remove sodium sulfate, sodium chloride, excess sulfuric acid, etc. The wet cake was then dried in a forced hot-air oven of 4.08-m^3 (144-ft^3) capacity at an inlet temperature of 125 to 135°C.

The dried Kepone was loaded in polyethylene-lined Fibre-pak drums of 91-kg (200-lb) capacity. An average of 2500 kg (5,500 lb) of Kepone, containing 5.2% water, was obtained from each batch processed, constituting an approximate conversion of 81% of the HCP to Kepone. An average analysis of the quality of Kepone produced is shown in Table III.1.

TABLE III.1. KEPONE BATCH RESIDUALS
(AMEEN, 1966)

	Wt%
Water	5.2
Methanol Insolubles	0.3
Sulfate	0.03
HCP	0.1
pH	6.0

Production Process at Life Science Products Company

Life Science Products Company, Inc. began production of Kepone soon after Allied ceased Kepone production in early 1974. The company was formed by an agreement with Allied, whereby Allied supplied raw materials to Life Science for Kepone production and paid a prearranged toll price for the Kepone product. This tolling type of operation allowed for capital recovery surcharges on the original plant and environmental control equipment subsequently installed. Life Science was provided operational instructions on Kepone processing by Allied and thus used approximately the same technology.

The Life Science process consisted of charging a dimerization reactor with 4300 kg (9500 lb) of HCP, 9.1 kg (20 lb) of antimony pentachloride catalyst and 0.64 kg (1.4 lb) of water. As in the Allied process, the reactor was heated to 60°C. Over a 2-hr period, 1450 kg (3200 lb) of SO_3 were added as the reactor temperature was allowed to rise to 100 to 105°C. The reaction was then held at this temperature and agitated until complete, an estimated 5 to 7 hr. After 5 hr, the reaction mixture sample was tested for completeness of reaction.

The quenching procedure was similar to Allied's, although 38,000 ℓ (10,000 gal) of water and 2500 ℓ (670 gal) of 50% NaOH were used. The solution was neutralized at 90°C with 360 kg (800 lb) of sulfuric acid to precipitate the Kepone. The precipitated Kepone slurry was sent to a rotary vacuum filter where the Kepone solids were removed onto the rotating filter cloth and washed with water prior to discharge from the filter. Damp Kepone dropped into the intake of the direct fired rotating tray (Wyssmont) dryer and was dried to a moisture level of about 5 wt%. Dried granular Kepone dropped directly from the dryer into 210-ℓ (55-gal) fiber-pak drums which were used to ship 102 kg (225 lb) net Kepone product.

Listed in Table III.2 are figures provided for the amount of production output of Kepone on a yearly basis.

TABLE III.2. PRODUCTION LEVELS OF KEPONE (FERGUSON, 1975)

	Production Output from Allied Semi-Works Plant	
Year	kg	lb
1966	35,935	78,125
1967	47,990	105,800
1968	36,535	80,550
1969	46,990	103,600
1970	41,460	91,400
1971	204,800	451,515
1972	176,970	390,150
1973	100,435	221,425
1974	72,260	159,300
Total		1,681,865

TABLE III.2. (continued)

Year	Production Output from Life Science Products Company	
	kg	lb
1974	385,370	849,000
1975	384,020	846,625
Total	769,390	1,696,225

SUMMARY CHRONOLOGY

Listed below is a chronology of relevant events that took place during the time Kepone was produced in Hopewell, Virginia. The events and dates listed are taken from the proceedings of the Senate Subcommittee Hearings on Kepone Contamination (1976). Although testimony is occasionally conflicting, the general chronology presented should provide a useful background summary.

1966 - March 1974	Intermittent manufacture of Kepone by Allied Chemical Corporation occurs at its Semi-works plant in Hopewell.
November 1973	Life Science Products Company, Inc. (LSP) signs agreement with Allied to produce Kepone on a toll processing contract basis. LSP receives permission from the city of Hopewell to discharge its future wastewaters into the city sewerage system.
March 1974	LSP begins production of Kepone. Malfuctions of production equipment allow the release of sulfur trioxide to the atmosphere. As a result, the Virginia Air Pollution Control Board cites LSP for failure to obtain a permit.
October 1974	On the basis of recommendations of the Virginia State Air Pollution Control Board, a baghouse collector is installed at the LSP plant. Complaints about emissions had occurred from February through August.

	During a survey of the Hopewell sewage treatment plant, the staff of the Virginia State Water Control Board discovers that the plant's digester is not operating properly. They learn that a chemical, Kepone, is being discharged into the city sewerage system.
	A meeting is held by the staff members of the city of Hopewell, the State Water Control Board (SWCB), the State Department of Health, and LSP. Staff of the SWCB state that the levels of Kepone discharged to the sewage treatment plant must be drastically reduced.
December 1974	The staffs of the SWCB and State Department of Health meet again with the city and LSP. The staffs inform them that further pretreatment of wastewater discharged by the company would be required to meet a limitation of 0.0077 kg (0.017 lb) of Kepone per day in the Hopewell sewage treatment plant effluent.
March 1975	A barrel of hexachloracyplopentadiene is added instead of sulfuric acid. Worker becomes ill from fumes.
April 9, 1975	The staff of the SWCB recommends amendments to the Hopewell NPDES permit. These amendments provide for limitations on Kepone in the sewage treatment plant effluent of 1.0 μg/ℓ, ppb, (maximum instantaneous concentration); 0.5 μg/ℓ, ppb, [daily average; 0.00758 kg/day (0.0167 lb/day) daily maximum]. The amendments also contain the condition that the city of Hopewell require LSP to pretreat effluent to a level of 100 μg/ℓ (ppb) Kepone, effective June 6, 1975.
April 1975	The city of Hopewell begins construction of an asphalt-sealed lagoon to contain the existing sludge from the plant which was thought to contain Kepone under requirements from the State of Virginia.
May 1975	Strong odor of hexachlorocyclopentadiene at the Hopewell sewage treatment plant causes an operator to seek medical attention. Sixty-eight kilograms (150 lb) of HTH are added to the sewer lines to oxidize the HCP. Little improvement is noted.

July 11, 1975	The Atlanta Center for Disease Control (ACDC) received the blood specimen of an LSP worker. An analysis of the blood reveals a 7.5 mg/ℓ (ppm) level of Kepone.
July 18, 1975	Virginia state officials are notified by the ACDC that Kepone has been detected in a blood sample taken from an employee of LSP.
July 22, 1975	Virginia state health officials conduct an inspection of the LSP operations and examine 10 employees working in the plant. Some of those examined have symptoms of neurological illnesses, with several being severe enough to require hospitalization. An inspection of the plant reveals air, ground, and building contamination by the product, Kepone, and the various compounds used in making Kepone.
July 24, 1975	The State Department of Health meet with officials of LSP. LSP management agrees to close the plant and comply voluntarily with all the conditions of the health department.

ESTIMATE OF TOTAL DISCHARGES

Losses From the Life Science Products Plant

From the preceding chronology it can be seen that there were numerous problems associated with production of Kepone at the Life Science Products plant. Subsequent investigations revealed that there were also significant discharges of Kepone from this facility. These losses were derived from four basic sources: (1) atmospheric releases from drying and bagging operations; (2) daily wastewater discharges; (3) acute wastewater releases due to spills, malfunctions, and bad batches; and (4) tank truck and solid waste loads dumped or routed to the terrestrial sites. Testimonies of former employees show that these releases from the Life Science plant involved several tons of the chemical through its year-and-a-half of production. However, without daily records, it is impossible to quantify these discharges. Evidence also indicates that Kepone was inadvertently carried home on workers' persons and clothes throughout the production period.

The best means of estimation would be a material balance based on raw hexachlorocyclopentadiene (HCP) supplied by Allied Chemical to the Life Science Products facility, the stoichiometry of product (81% yield), and outputs returned to Allied. By differences, the order of magnitude of total discharges could be ascertained, i.e.:

$$\text{Losses} = 0.81 \text{ x } (\text{Theoretical Yield of HCP Supplies}) - \text{Sales}$$

However, Allied Chemical has deemed it inappropriate to release data, which would assist in making an accurate appraisal, since litigation is continuing. Without that information, total losses can only be estimated. This has been accomplished in the following manner. Life Science Products originally had a design capacity of 1400 kg/day (3000 lb/day) when production began in March 1974. In March 1975, a second dryer was added to the operation to double the capacity. Since there was continual pressure to maximize output, production was generally above the design capacity. Testimony by Mr. Virgil Hundtofte at the Senate Hearings on Kepone Contamination suggests average production was about 1800 kg/day (4000 lb/day) during the initial period when design capacity was 1400 kg/day (3000 lb/day). Over 2700 kg/day (6000 lb/day) were produced at the expanded capacity when the second dryer was installed. Testimony further confirms that production continued 24 hr a day, 7 days a week (Senate Hearings, 1976). It is assumed that operations were at a 1800 kg/day (4000 lb/day) level for 11 months and at a 2700 kg/day (6000 lb/day) level for 5 months. One month of 1400 kg/day (3000 lb/day) production was probably lost with installation of centifuges and the holding tank during the spring of 1974, and into October when the baghouse was finally installed.

Thus, total potential production at the Life Science Products Plant is estimated at:

1800 kg/day (4000 lb/day) x 304 days = 550,000 kg (1,216,000 lb)
2700 kg/day (6000 lb/day) x 115 days = 311,000 kg (690,000 lb)
861,000 kg (1,906,000 lb)

Company records detail product output of 770,000 kg (1,700,000 lb) (Ferguson, 1975) sold to Allied Chemical during that period. If the difference is assumed to represent Kepone losses, there was a total potential discharge of:

867,000 kg (1,910,000 lb) Potential Production
-772,000 kg (1,700,000 lb) Sales to Allied
95,000 kg (210,000 lb)

Therefore, maximum potential losses from the Life Science Products operation are estimated at 90,000 kg (200,000 lb).

Losses From the Allied Semi-Works Plant

It is even more difficult to quantify the discharges of Kepone during the period that Allied Chemical Corporation was producing the chemical from 1966 to 1974. Indications are that Allied's production was more efficient and clean with respect to worker safety and workroom exposure. Reasons for this include reduced production and a drying process that created fewer atmospheric releases relative to the Life Science Products process. According to Epstein (1978) there is little basis to substantiate inferences as to alleged better production practices at Allied. Environmental samples taken prior to 1974 reveal Kepone contamination in the James River before the start-up of the Life Science Products Company plant. Nichols and Tratmen (1977) report sediment samples collected in May 1967 from the Jamestown Dancing Point reach contained 0.038 and 0.018 μg/g (ppm) Kepone. Kepone concentrations in preserved samples of fish and oyster tissue are presented in Table III.3. These confirm contamination prior to 1974. The bluefish levels are of particular interest since they indicate as high a contamination in 1973 as any of the data taken in 1977. Similarly, data presented in Table IV.4 on Kepone levels in avian predators reveal contamination in James River eagles as early as 1970.

RESIDUAL KEPONE DISPOSITION DURING THE LIFE SCIENCE PRODUCTION PERIOD

Atmospheric Releases

Production at the Life Science Products plant resulted in significant releases of particulate Kepone into the atmosphere. During the period of operation, March to October 1974, complaints were received on these particulate emissions. Local citizens stated that on a windy day drivers needed to turn their car lights on to proceed through the white cloud at the plant site. The ensuing complaints led to State action requiring installation of a bag-house filter in October. Subsequent analysis of preserved filters from State-operated air sampling stations revealed contamination of the particles at levels of up to 40% Kepone with detectable levels measured at distances of up to 25 km (16 mi) from Hopewell. Calculations have shown levels of 0.2 to 50 μg Kepone/m^3 of air during the period March 1974 to April 1975.

Discharges to the Sewer System

Daily wastewater discharges from Life Science Products passed through the Station Street pumphouse, then to the sewage treatment plant where they were subjected to primary treatment and finally discharged to Bailey Creek. Analysis of the few samples available revealed wastewater discharges from the Life Science Products plant contained from less than 1 to 36.9 mg/ℓ (ppm). Samples of the treatment plant effluent and sludge also contained Kepone. Analysis of one of the digesters revealed a level of 68 mg/ℓ (ppm) in digester sludge (Senate Hearings, 1976).

Initially, the sludge was disposed in Hopewell's landfill. However, after concern developed over the contamination of the sludge it was decided to contain the sludge to prevent the leaching of Kepone. In May 1975 the Kepone lagoon was completed on the grounds of the sewage treatment plant and the sludge from the digester was placed in it. The lagoon is a 33.5-m (110-ft) by 58-m (190-ft) rectangular holding pond formed by earthen dikes placed at a maximum 1:1 grade with gentler slopes in the southern corner.

TABLE III.3. KEPONE CONCENTRATIONS IN FISH AND OYSTER TISSUES*

Species	Number of Samples	Date	Location	Average Kepone Concentration (ppm)	Standard Deviation
Fish					
Menhaden	1	6/2/73	Zone G	0.49	---
Spot	1	6/2/73	Zone G	0.036	---
Bluefish	2	6/2/73	Zone G	0.437	0.57
Bluefish	4	6/10/73	Zone A	0.62	0.44
Bluefish	8	6/9/76	Zone A	0.23	0.11
Bluefish	21	6/18/77	Zone A	0.41	0.27
Shellfish					
Oyster	11	6/2/67	Deep Water Shoals	0.10	0.03
Oyster	3	8/8/68	Nansemond Ridge	0.015	0.003
Oyster	4	10/28/68	Deep Water Shoals	0.074	0.01
Oyster	4	12/20/68	"	0.12	0.02
Oyster	4	2/28/69	"	0.10	0.01
Oyster	5	3/18/69	Nansemond Ridge	0.025	0.005
Oyster	4	6/12/69	"	0.026	0.007
Oyster	11	8/27/69	Deep Water Shoals	0.21	0.005
Oyster	4	7/20/70	"	0.12	0.01
Oyster	4	7/20/70	Nansemond Ridge	0.022	0.003

---

* Fish data from information on file at the Virginia State Water Control Board. Oyster data from letter to Dr. R. J. Huggett, Virginia Institute of Marine Science from Dr. E. O. Oswald, U.S. EPA Research Triangle Park, April 27, 1976.

It has a maximum depth of 2.13 m (7 ft) and is reportedly lined with a layer of clay and two layers of gravel impregnated with asphaltic tar (Koerner et al., 1976). Conversations with city staff and observations indicate that the liners may actually be something less than designed. Several areas display loose gravel where tar was not applied or quickly lost its integrity. In addition, sludge and soil deposits have sponsored plant life which now abounds in the south end of the lagoon and has decreased depth in that zone to 3 ft. Initial analyses concluded that the lagoon held 5700 m^3 (1.5 million gal) of sludge containing 3 to 5% solids. The liquid contained approximately 2 mg/ℓ (ppm) Kepone, the solids 200 to 600 μg/g (ppm) (Sterrett and Boss, 1977). The relative location of these sites and State ground-water monitoring wells is illustrated in Figure III.6.

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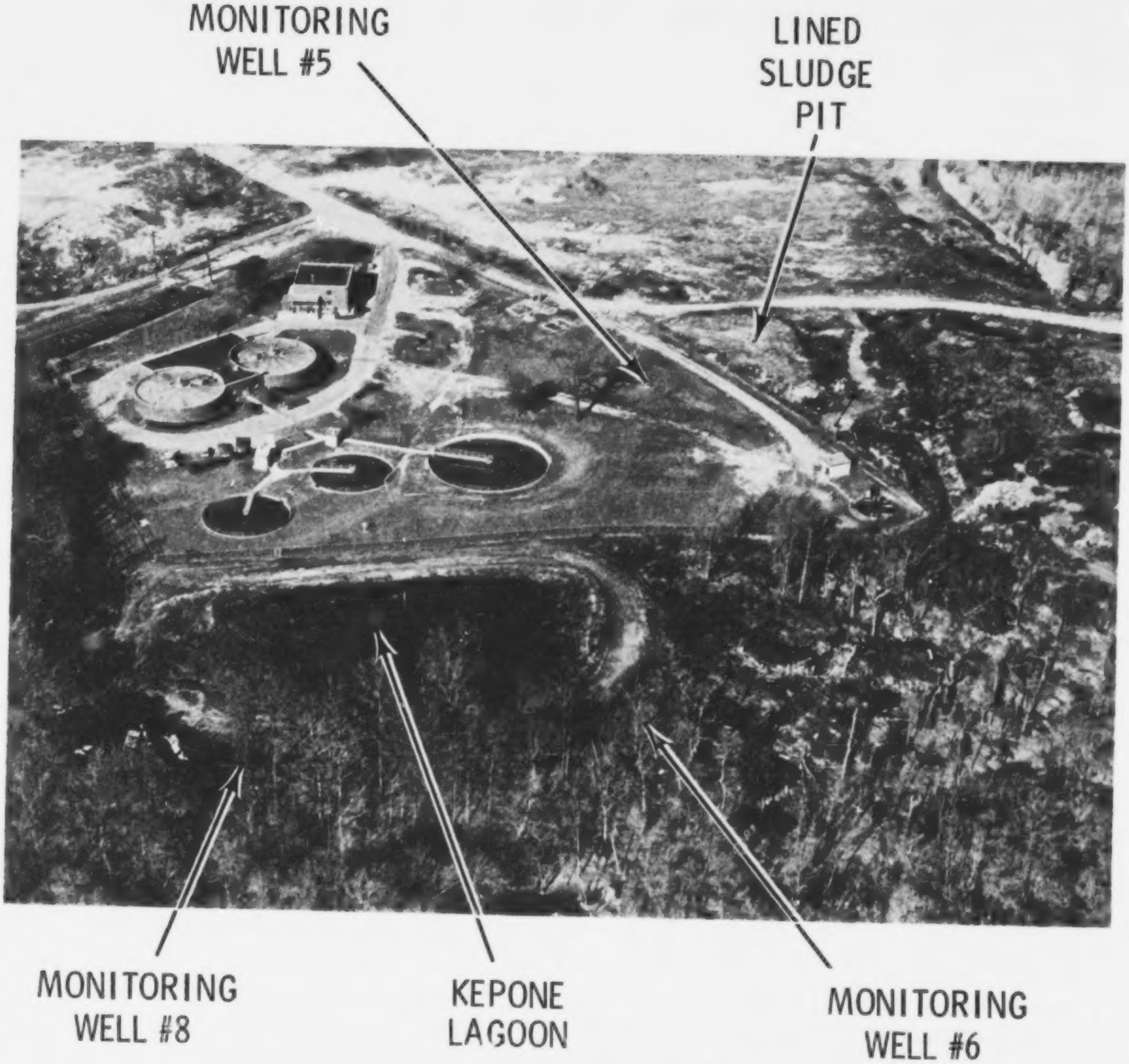

MONITORING WELL #5
LINED SLUDGE PIT
MONITORING WELL #8
KEPONE LAGOON
MONITORING WELL #6

FIGURE III.6. The Kepone Lagoon Area

Bulk Discharges

Accidental releases and intentional batch dumps of Kepone followed one of several routes: (1) flow into the sewer with daily discharges; (2) transport and disposal on land (3) discharge down manholes; and (4) transport out on workers' clothes and persons. The first method appears to have occurred during the early production history of Life Science Products. Trucking to dump sites began after scrutiny of wastewater discharges by the SWCB. Two areas were identified as the main land disposal sites for dumping Kepone residuals by Life Science Products. These are the Hopewell landfill (Figure III.7) which reportedly received contaminated solid waste as well as an off-spec batch that did not meet Allied Chemical's specifications, and the former Allied Pebbled Ammonium Nitrate (PAN) plant south of State Highway 10, west of Bailey Creek (Figure III.2).

The PAN site was used for contaminated wastewater disposal following investigations by officials into the problem of Kepone in the city sewer system in late 1974. Wastewater was regularly trucked to the PAN site and discharged into a 1.2-m (4-ft) deep trench, where it percolated into the soil. No data exist that quantify the actual amount of water discharged nor its concentration of Kepone.

DISTRIBUTION OF KEPONE RESIDUALS FOLLOWING CESSATION OF PRODUCTION

The Atmospheric Compartment

Continued monitoring of air in the Hopewell area after Life Science Products facility was closed revealed a decline in ambient Kepone concentrations to nondetectable levels. Consequently, the atmospheric compartment probably held Kepone for a transient period only and should not be considered as a major sink for residuals. Recurring levels may occur if weather conditions stimulate resuspension but no such data have been reported.

The Water Compartment

Water has also been considered a transient sink for Kepone. Kepone partitions in water/sediment systems with a strong affinity for particulates. Elutriate data from laboratory tests (described in Chapter IV) and sorption-desorption evaluations suggest a partition coefficient on the order of 10^{-4} (concentration in water to concentration in sediment). Hence, only a small fraction of total residual Kepone will be present in water in systems with high solid levels. Early environmental sampling revealed levels of 1 to 4 μg/ℓ (ppb) in Bailey Creek, 0.1 μg/ℓ (ppb) in the Appomattox River, and 0.3 μg/ℓ (ppb) in the James River near the mouth of Bailey Creek (Smith, 1976). More recent data suggest that Kepone levels in most of the James River are below detectable levels of 0.01 μg/ℓ (ppb) (Huggett et al., 1977).

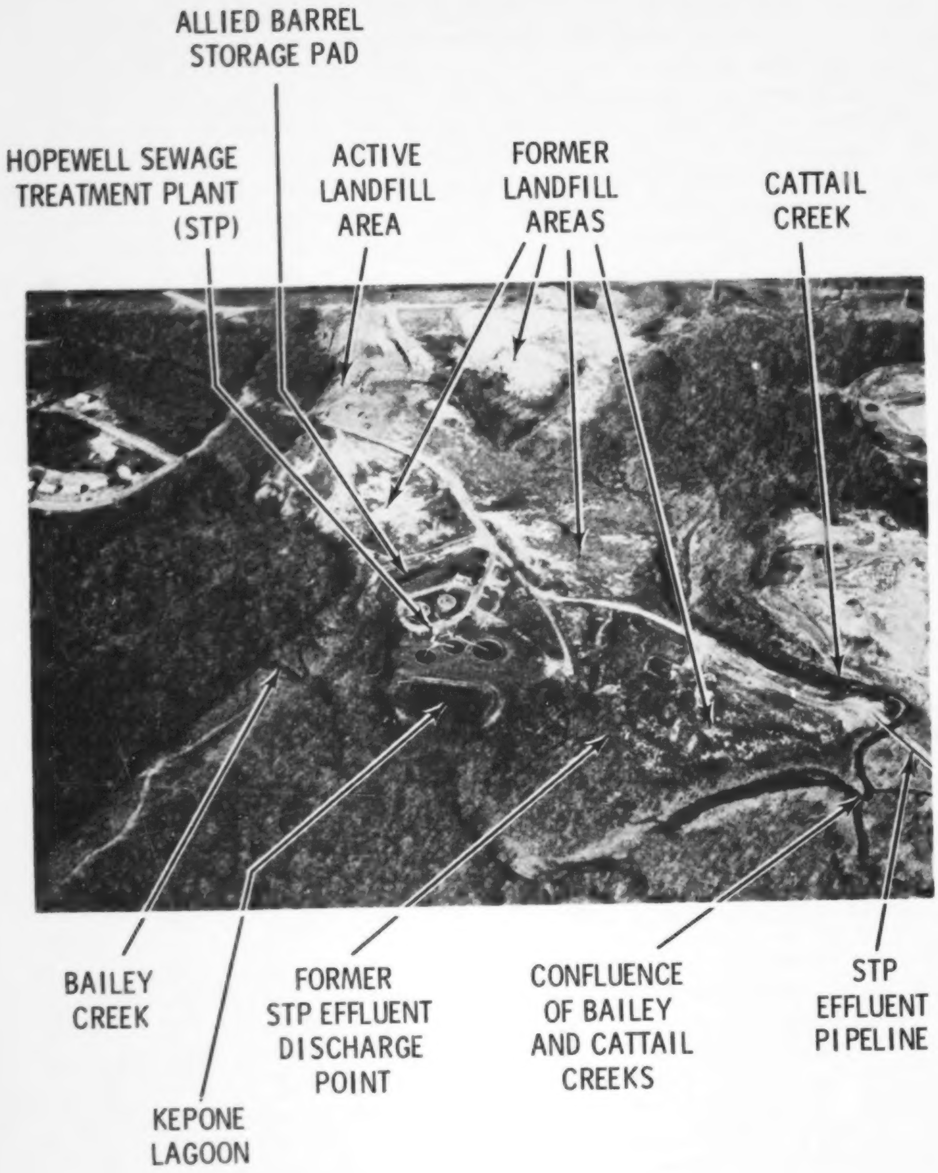

ALLIED BARREL STORAGE PAD
HOPEWELL SEWAGE TREATMENT PLANT (STP)
ACTIVE LANDFILL AREA
FORMER LANDFILL AREAS
CATTAIL CREEK
BAILEY CREEK
KEPONE LAGOON
FORMER STP EFFLUENT DISCHARGE POINT
CONFLUENCE OF BAILEY AND CATTAIL CREEKS
STP EFFLUENT PIPELINE

FIGURE III.7. The Hopewell Landfill and Sewage Treatment Plant

Kepone has been found in ground-water systems periodically. Historical data for monitoring wells are reviewed in Table III.4. The locations of these wells can be found in Table III.5 and Figure III.8. The fluctuations noted in Table III.4 support the contention that water acts as a transient sink for Kepone during its movement between solid substrates. However, caution is warranted in that most of the monitoring wells were not perforated over their depth and therefore only draw water from the screened bottom of the casing. In many locations, this situation may represent a low aquifer isolated by clay layers from the uppermost aquifer, which is likely to be the most Kepone-contaminated.

Sewage Treatment Plant Effluent

Effluent levels of Kepone from the sewage treatment plant have been monitored at Hopewell since 1976, first on a weekly basis (through March 1977) and then on a monthly basis. Results taken from files at the Hopewell sewage treatment plant are given in Table III.6. The levels have ranged from 0.04 to 5.26 μg/ℓ (ppb). In April 1977, dry weather Kepone levels increased to 0.56 μg/ℓ (ppb) and consistently stayed above 0.5 μg/ℓ (ppb) through September. The significance of these levels must be reviewed in comparison to the tentative guideline set by the State Water Control Board in 1974 of 0.4 μg/ℓ (ppb) Kepone in effluents (Senate Hearings, 1976).

Samples taken from portions of the sewer system reveal contamination along the route from the Life Science Products site to the sewage treatment plant. Solids collected from the main pump station contained 68 μg/g (ppm) Kepone, while residual material from the grit chamber held 37 μg/g (ppm) Kepone (Annapolis, 1976).

Soils and Sediment

Following the closure of the Life Science plant, the soil and sediments in the area held the bulk of the Kepone residuals. In the immediate vicinity of the plant, Kepone was measured at levels as high as 1 to 2% (10,000 to 20,000 ppm). These declined to 300 ppm at sites due east of the plant and 2 to 6 ppm at 1000 m (3300 ft) (EPA, 1975). It has been estimated that as much as 1 metric ton may have been deposited in an area around the plant within a radius of 1000 m (3300 ft) (Blanchard, 1976). This estimate is based on seven samples in the area. The bulk of contributing residues were on the plant site itself.

Surface and subsurface soil samples were collected when the State Water Control Board drilled monitoring wells in early 1975. The results of Kepone measurements in the surface samples are displayed in Figure III.9. Most of the surface samples contained detectable levels of Kepone, with a general pattern of decreased concentration with increased distance from the Life Science site.

TABLE III.4. HISTORICAL DATA ON REPORTED KEPONE CONCENTRATIONS IN MONITORING WELL WATER (μg/ℓ-ppb)

Date (Laboratory) Days	Well No. 10 Nitrogen Park	Well No. 12 N&W Railroad	Well No. 7 Landfill NW	Well No. 2 Kepone Disposal Pit	Well No. 8 Kepone Lagoon 5	Well No. 5 Landfill N	Well No. 3 Bailey Creek	J. W. Quick Well Across Bailey Creek	RA Fleetwood Well	Jack Bolander Well River's Edge Sub.	Jordan Yacht Marine	Domestic Well King George County	J. Vaughn Well Turkey Island	Well No. 11 Hopewell News	D. A. Long	Well No. 6 Sludge Lagoon N	Well No. 9 Pump Station Hopewell Landfill
1976																	
January (SWCB) 7, 9				0.07				0.05		0.09	0.04						
February (SWCB) 17, 19, 25	0.04	0.04		0.02								ND		ND			
March (SWCB) 4, 23-25				ND		ND		0.10		ND			0.04				
April (SWCB) 12, 13, 21	0.06	0.02	ND	ND	ND	0.01								ND		ND	ND
May (SWCB) 18, 19	3.0	0.04	ND	3.40													
June (SWCB) 7, 8, 18, 23	ND	0.07	ND	ND	ND	ND	ND	ND					ND	ND	ND		
July (SWCB) 20, 21, 27, 28	0.08	0.06	ND	ND	ND	0.03	ND	ND		ND			0.03	ND	ND		ND
1977																	
February (SWCB) 3	0.05	ND	ND		ND	ND	ND							ND			
March (SWCB) 11	ND	ND	ND	ND	ND	ND	ND							ND			
June (SWCB) 2	ND	ND	ND	ND	ND	ND	ND										
July (SWCB) 14	ND	ND	ND	ND		ND	ND										

SWCB - Virginia State Water Control Board - Source Kepone Data Bulletins 10, 18, 29, 35, 55, 67, 69, and addenda.

TABLE III.5. LOCATION OF MONITORING WELLS

Well No.	Location
2	Kepone Disposal Pit
3	Bailey Creek
4	PAN Site
5	Landfill North
6	Sludge Lagoon North
7	Landfill Northwest
8	Sludge Lagoon South
9	Hopewell Landfill
10	Nitrogen Park
11	Hopewell News
12	N&W Railroad
Quick	J. W. Quick Well Across Bailey Creek
Jordan	Jordan Point Yacht Marina

Only two corings showed Kepone at depth: (1) Well 10 at Nitrogen Park, and (2) Well 6 at the Kepone lagoon. At Nitrogen Park, the 15 μg/g (ppm) surface soil Kepone level was followed by 0.21 μg/g (ppm) and 0.19 μg/g (ppm) at 4.9 m (15 ft) and 6.5 m (20 ft), respectively. At the lagoon well, the 0.18 μg/g (ppm) Kepone content on the surface was underlain by a measured concentration of 0.26 μg/g (ppm) Kepone at 3.3 m (10 ft).

Limited samples were also taken by State field staff. Three composites from the PAN site below the site of the covered-over disposal trench were found to contain 0.20 μg/g (ppm) (12 in. composite), 1.40 μg/g (ppm) (3-ft composite), and 71 μg/g (ppm) (5-ft composite), respectively (SWCB Bulletins, 1976). A 5-ft composite sample taken from the vicinity of the trench in July 1976 contained 27,000 μg/g (ppm) Kepone.

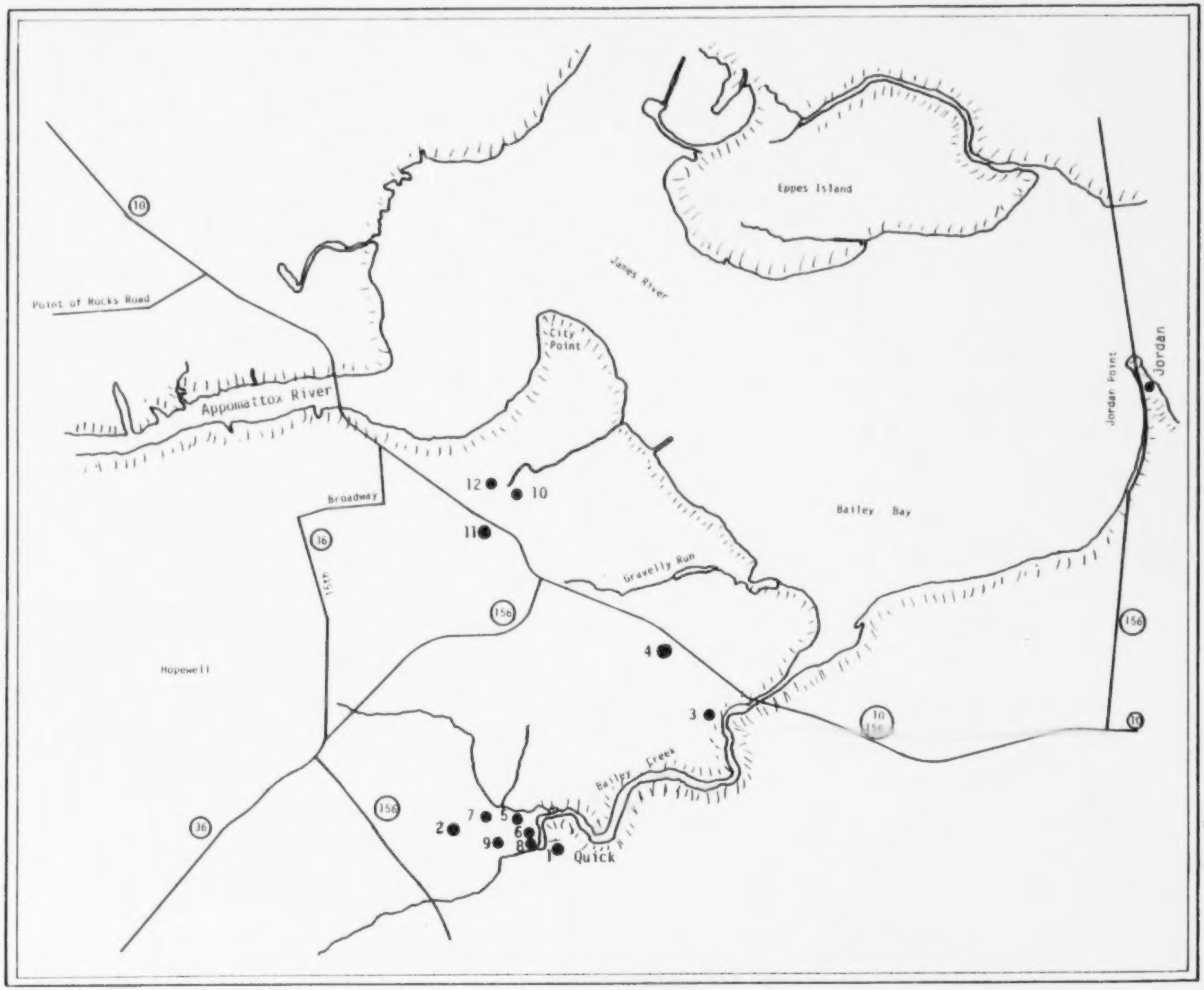

Eppes Island
James River
Point of Rocks Road
10
City Point
Jordan
Jordan Point
Appomattox River
12
10
Broadway
Bailey Bay
36
11
Gravelly Run
15th
156
156
4
Hopewell
3
10
156
10
Bailey Creek
156
7
5
2
6
9
8
1
Quick
36

FIGURE III.8. Location of Monitoring Wells in Hopewell Area

TABLE III.6. CONCENTRATION OF KEPONE IN THE HOPEWELL STP EFFLUENT AS REPORTED BY THE CITY OF HOPEWELL

1976		1977	
7/14	0.24 ppb	1/4	0.16 ppb
7/20	0.24	1/11	0.81
7/27	0.24	1/18	0.49
8/3	0.23	1/25	0.13
8/10	0.16	2/1	0.04
8/17	0.14	2/8	0.57
9/7	0.14	2/15	4.54
9/14	0.12	2/22	0.38
9/21	0.11	3/1	0.12
9/30	0.20	3/8	0.10
10/12	0.18	3/15	0.07
10/19	0.07	4/5	0.56
10/20	3.31	5/3	0.65
10/26	0.96	6/7	0.59
11/2	0.07	7/5	5.26
11/9	0.26	8/2	0.49
11/16	3.02	9/6	1.15
11/23	1.68		
11/30	1.09		
12/7	0.93		
12/14	0.26		
12/21	0.36		
12/28	0.33		

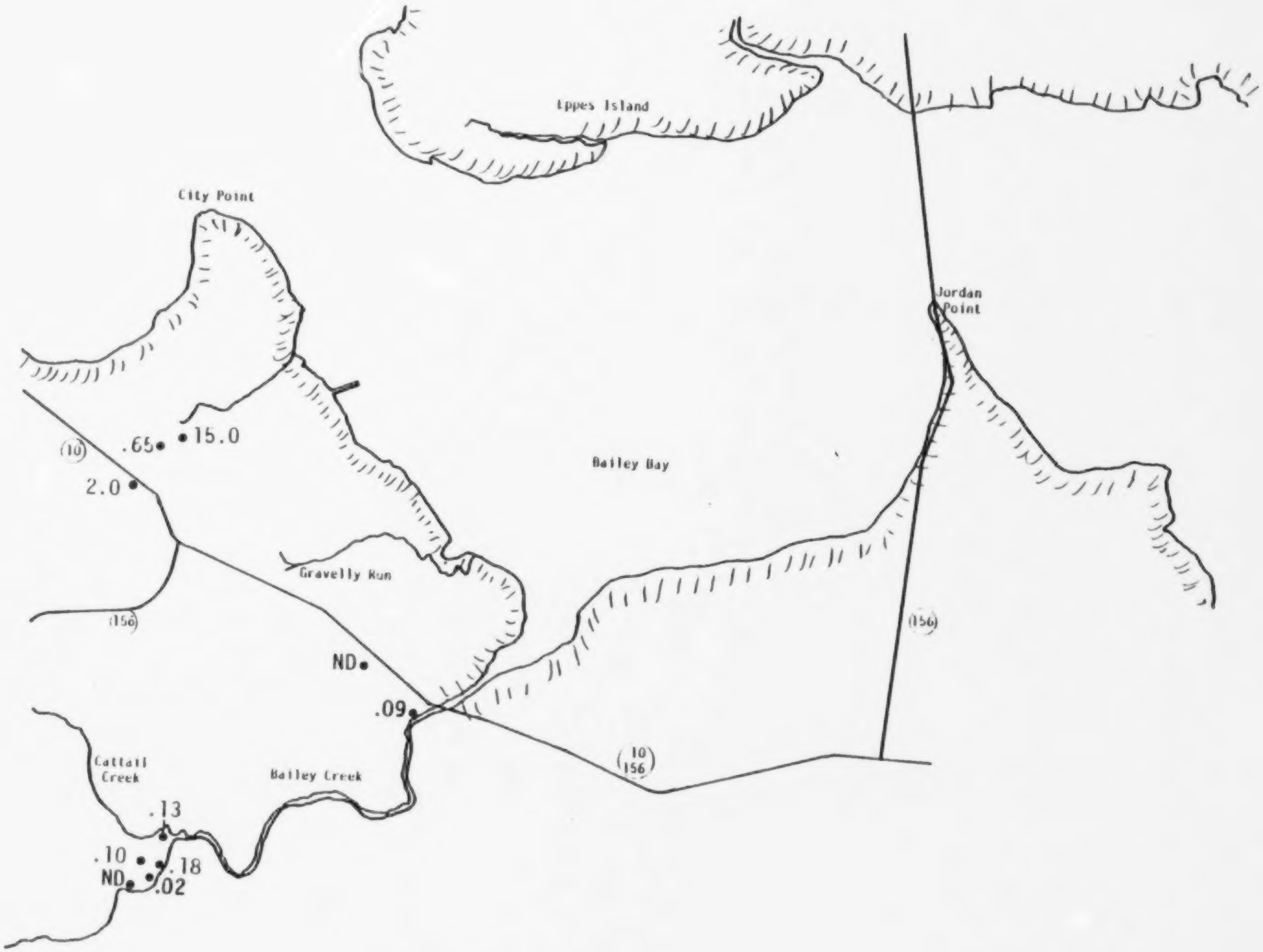

Eppes Island
City Point
Jordan Point
Bailey Bay
Gravelly Run
Cattail Creek
Bailey Creek
(10)
(156)
(10/156)
.65
15.0
2.0
ND
.09
.13
.10
.18
ND
.02

FIGURE III.9. Kepone Levels in Soil - 1975-1976 as Noted in SWCB Bulletins and Files (µg/g-ppm) (Composite Soil Samples were Collected at PAN Plants)

Data on sediment concentrations are more prevalent. Composite (top 12 in.) sample values range up to 10 ppm in Bailey Bay. A graphic display of concentration zones reported for 1976 can be found in Figures III.10 through III.12. The Virginia Institute of Marine Science (VIMS) has extrapolated these data to estimate that a total of 47,000 kg (103,000 lb) lies at the bottom of the James River (Chigges, 1977). A similar display of data including later sampling points can be found in Figures III.13 through III.15. These data have been generated from detectable levels reported by the State Water Control Board, VIMS, and other sources catalogued in Appendix B. Shading was added to connect points of similar Kepone concentration. Samples where Kepone was nondetectable were not mapped. Hence, the maps represent a worst case estimate. It appears from these that contamination from upstream sediments has moved downstream. The extent of this movement and its implications is of vital importance in assessing the current situation and the need for remedial action. Caution is necessary in interpreting differences in the maps, however, since the later data reflect heavier sampling frequencies and new sampling sites not reflected in the earlier work, as well as the omission of intermediate points where Kepone was nondetectable.

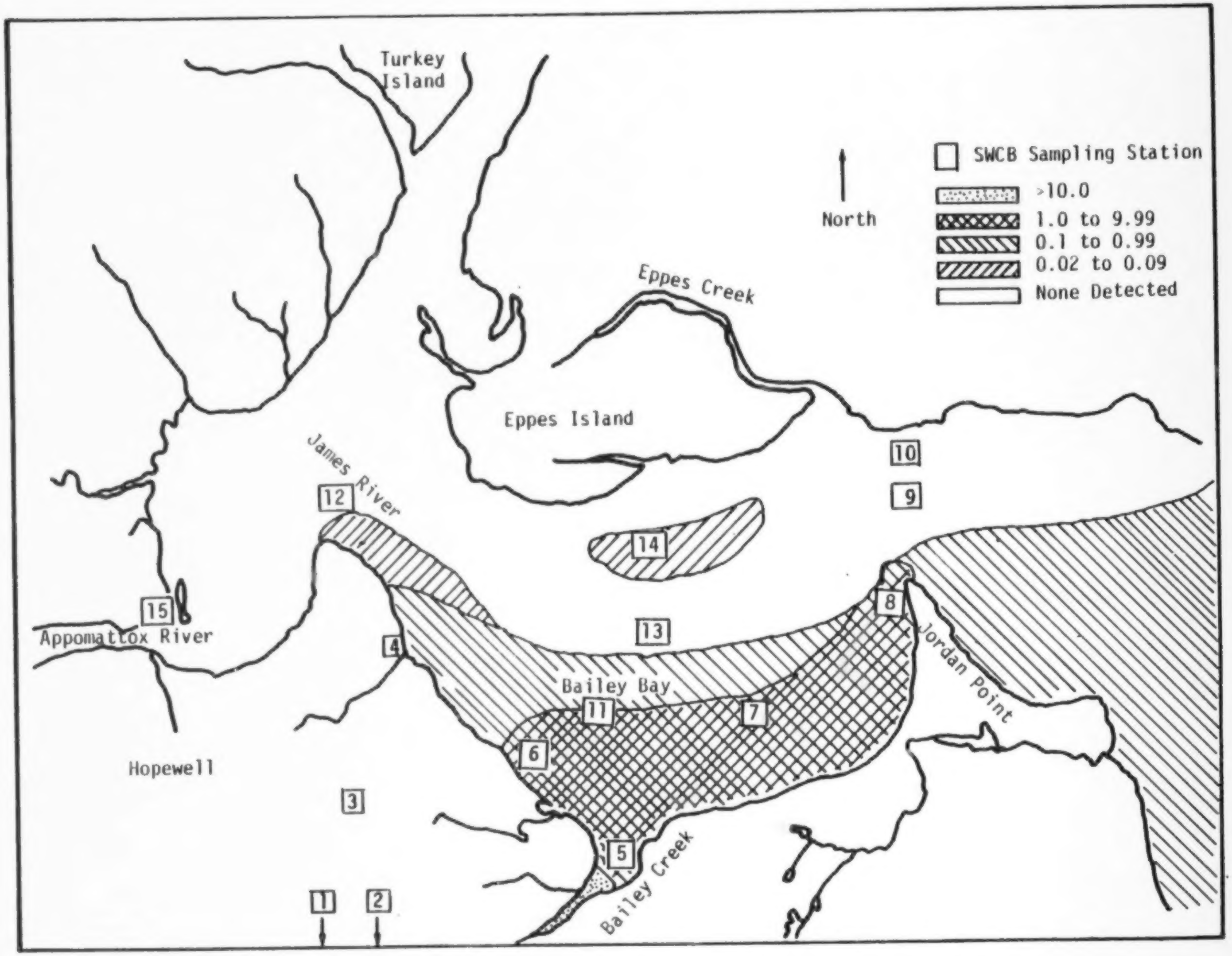

Turkey Island
SWCB Sampling Station
North
>10.0
1.0 to 9.99
0.1 to 0.99
0.02 to 0.09
None Detected
Eppes Creek
Eppes Island
James River
10
9
12
14
15
Appomattox River
13
8
Jordan Point
4
Bailey Bay
11
7
6
Hopewell
3
5
Bailey Creek
1
2

FIGURE III.10. James River Sediment Kepone Concentrations in the Vicinity of Hopewell, Virginia Based on Data Collected in 1976 by the State Water Control Board (Chigges, 1977)

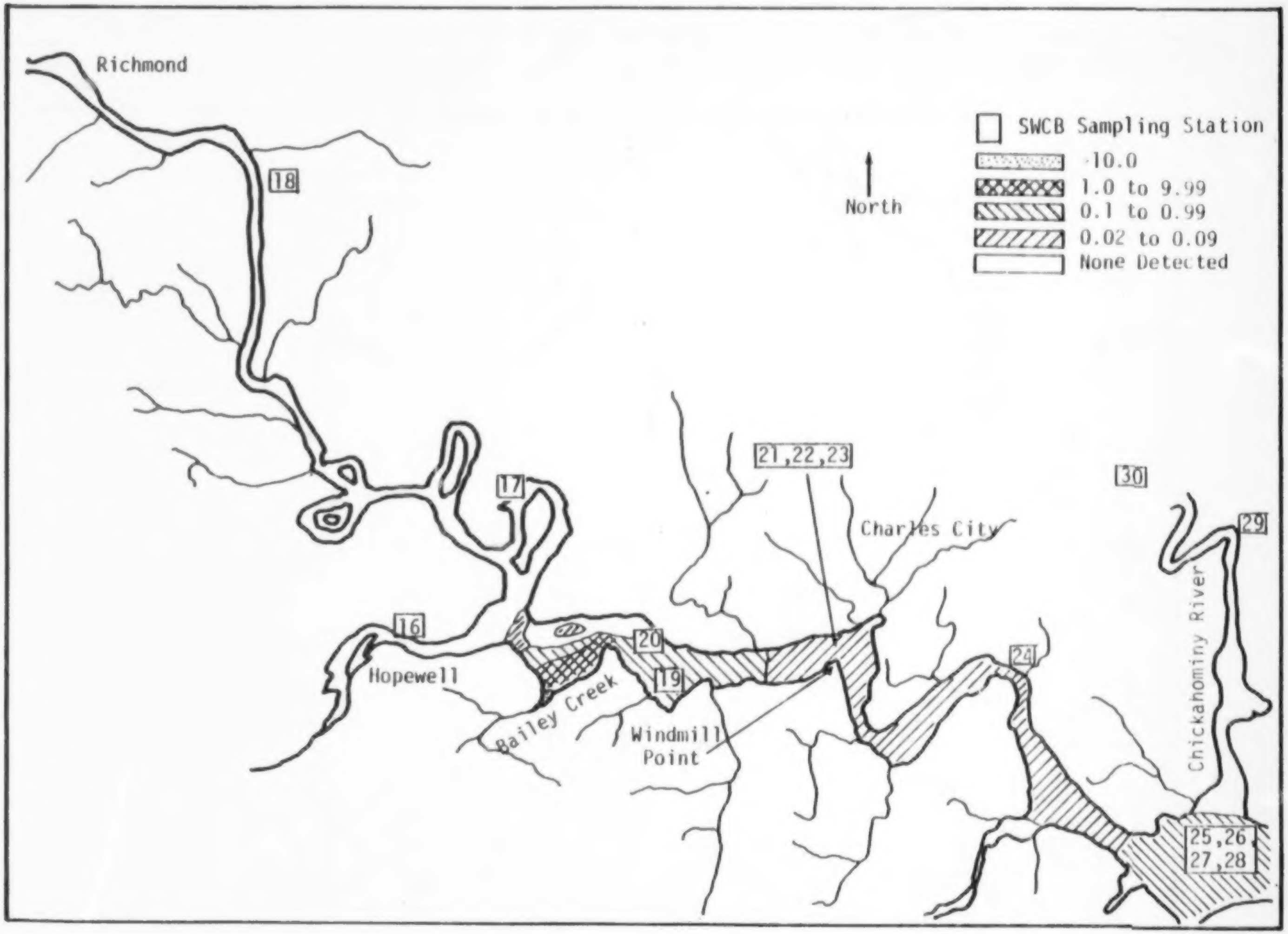

Richmond
SWCB Sampling Station
>10.0
1.0 to 9.99
0.1 to 0.99
0.02 to 0.09
None Detected
North
18
17
16
Hopewell
Bailey Creek
20
19
Windmill Point
21,22,23
Charles City
24
30
29
Chickahominy River
25,26
27,28

FIGURE III.11. James River Sediment Kepone Concentrations from Richmond, Virginia to the Mouth of the Chickahominy River Based on Data Collected in 1976 by the State Water Control Board (Chigges, 1977)

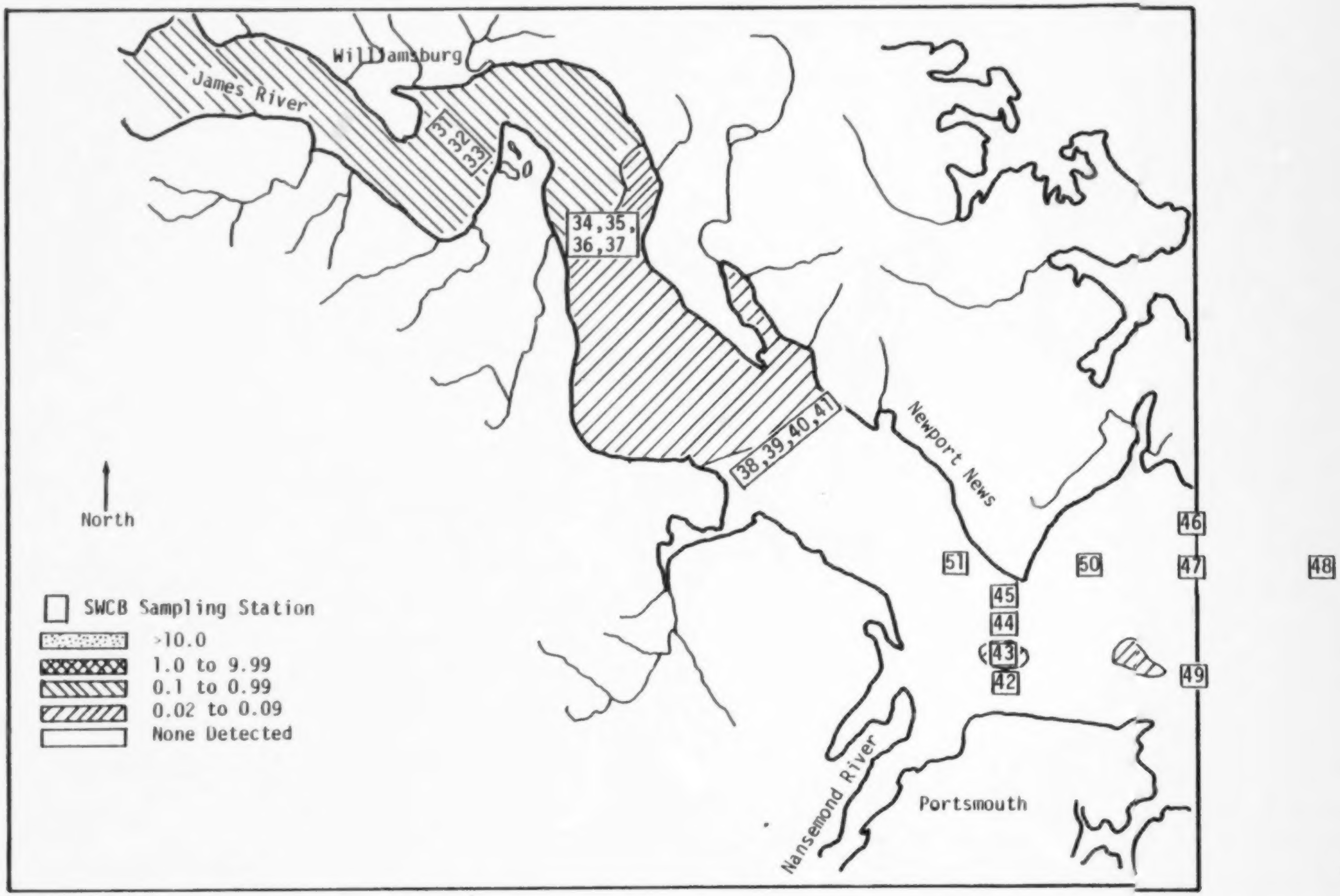

Williamsburg
James River
31, 32, 33
34,35, 36,37
38,39,40,41
Newport News
Nansemond River
Portsmouth
42
43
44
45
46
47
48
49
50
51
North
SWCB Sampling Station
>10.0
1.0 to 9.99
0.1 to 0.99
0.02 to 0.09
None Detected

FIGURE III.12. James River Sediment Kepone Concentrations from Williamsburg, Virginia to Newport News Based on Data Collected in 1976 by the State Water Control Board (Chigges, 1977)

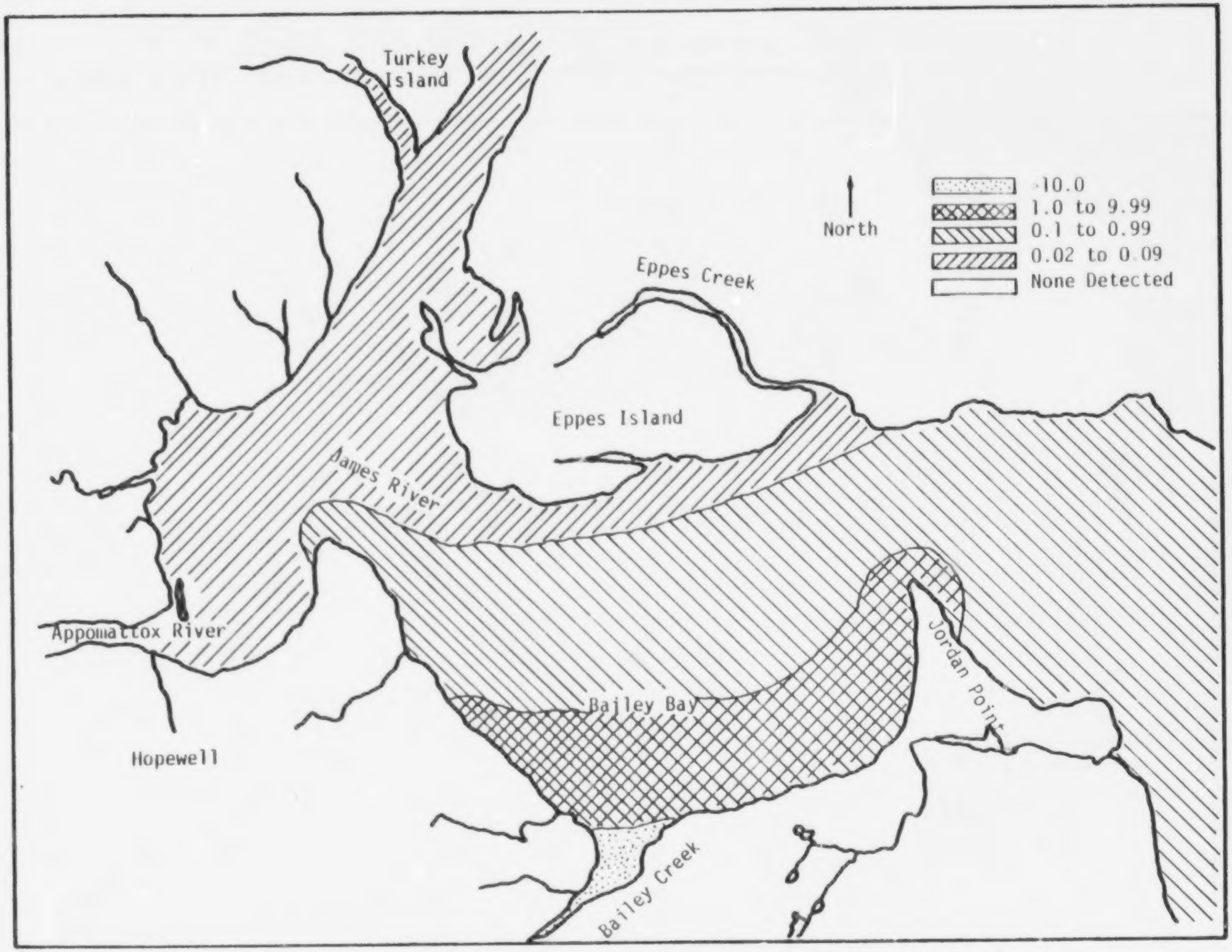

Turkey Island
North
>10.0
1.0 to 9.99
0.1 to 0.99
0.02 to 0.09
None Detected
Eppes Creek
Eppes Island
James River
Appomattox River
Hopewell
Bailey Bay
Jordan Point
Bailey Creek

FIGURE III.13. James River Sediment Kepone Concentrations from Richmond, Virginia to the Mouth of the Chickahominy River Based on Data from 1976 and Early 1977

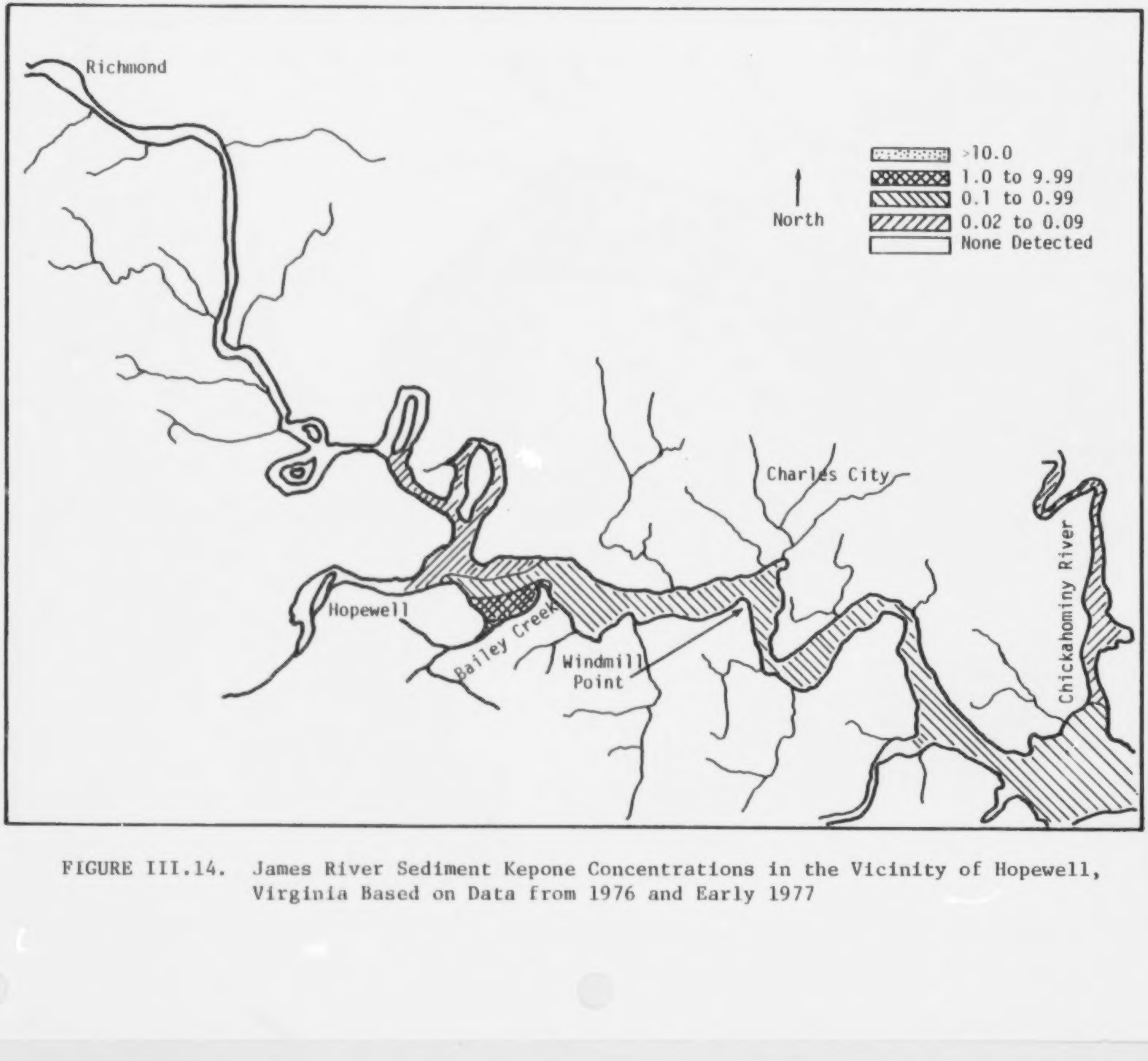
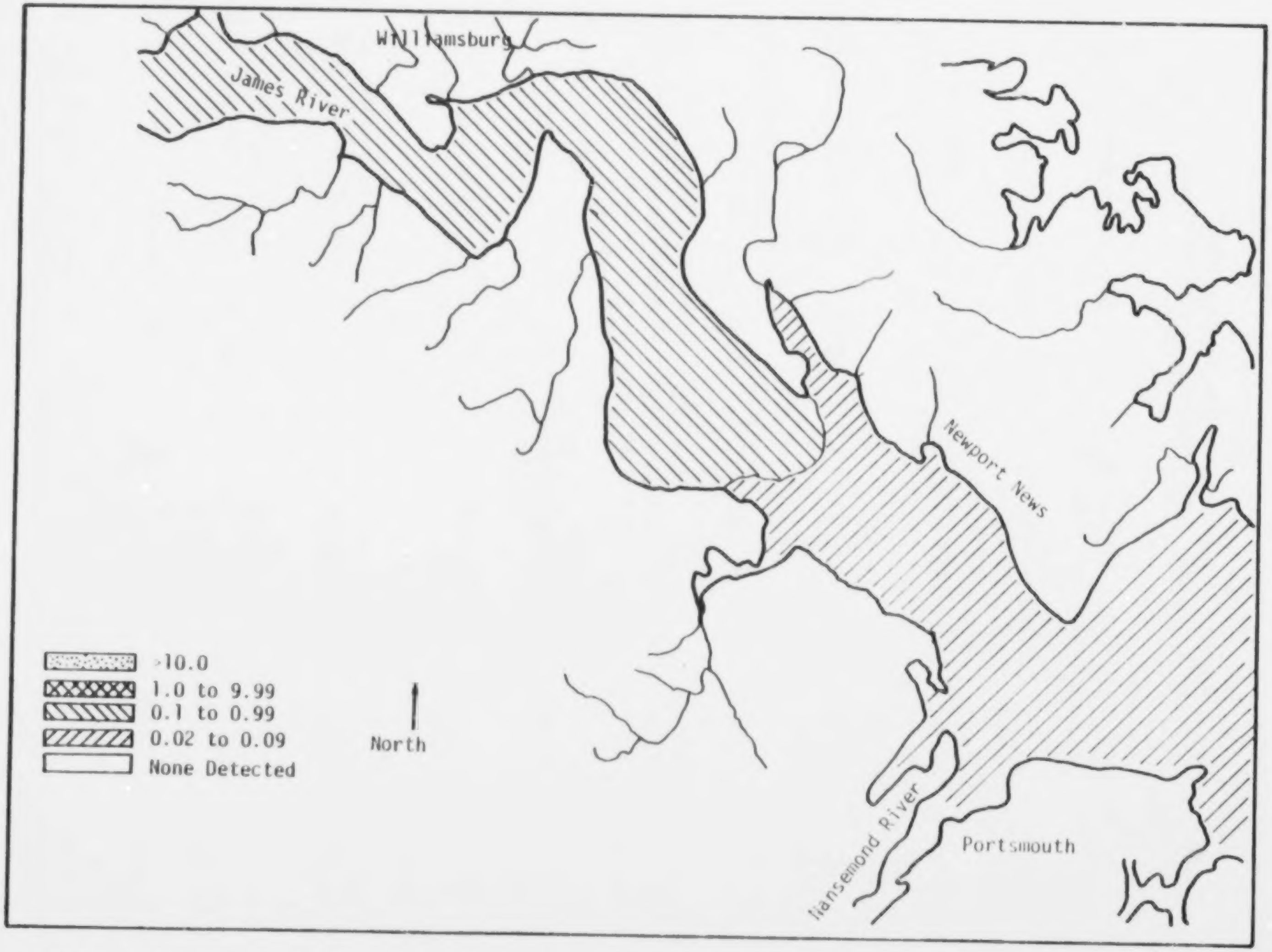

Richmond
North
▨ >10.0
▨ 1.0 to 9.99
▨ 0.1 to 0.99
▨ 0.02 to 0.09
☐ None Detected
Charles City
Hopewell
Bailey Creek
Windmill Point
Chickahominy River

FIGURE III.14. James River Sediment Kepone Concentrations in the Vicinity of Hopewell, Virginia Based on Data from 1976 and Early 1977



Williamsburg
James River
Newport News
Nansemond River
Portsmouth
North
▧ >10.0
▩ 1.0 to 9.99
▨ 0.1 to 0.99
▨ 0.02 to 0.09
☐ None Detected

FIGURE III.15. James River Sediment Kepone Concentrations from Williamsburg, Virginia to Newport News Based on Data from 1976 and Early 1977

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CHAPTER IV - PROPERTIES OF KEPONE

SUMMARY

Content

Chapter IV begins with a discussion of the chemical properties of Kepone, and leads to an appraisal of the movement and persistence of the chemical in the natural environment. The pathways of Kepone movement, including volatilization and sorption/desorption, are examined, followed by analysis of biological translocation. This section includes Kepone uptake in aquatic organisms, avian predators, and plants. Finally, degradation of Kepone through biochemical and photochemical mechanisms is discussed.

Findings

- Kepone is strongly sorbed onto soil and sediment particles such that at equilibrium in the environment, concentrations on particulate matter are 10^4 to 10^5 times those in the surrounding water.

- Laboratory and field observations indicate that Kepone does not volatilize to any significant extent.

- Kepone's solubility is a direct function of solution pH. Kepone levels in leachate from sediments with 1 μg/g (ppm) Kepone increased from 0.031 μg/ℓ (ppb) at a pH of 7.2 to 6.84 μg/ℓ (ppb) at pH 12.0.

- Algae from the James River have been found to contain Kepone concentrations above the level required to adversely affect productivity (0.35 to 1.0 μg/g).

- Kepone was bioconcentrated by laboratory oysters, mysids, and spot from sea water containing less than 0.03 μg/ℓ (ppb) Kepone.

- Bird species in which Kepone residuals have been detected include the great blue herron, mallard duck, coot, black duck, wood duck, herring gull, Canadian goose, hooded mersanger, and bald eagle.

- Experiments indicate that plants sorb Kepone in their roots but do not transport it upward through the stem and leaf compartments.

- There is no evidence to date of Kepone degradation in the natural environment.

INTRODUCTION

In order to investigate the ultimate fate of Kepone in the environment, it is first necessary to understand the nature of the chemical and the mechanisms which move it through the environment. Mechanisms include natural pathways, biological translocation, and degradation.

BASIC CHEMISTRY OF KEPONE

Kepone is a representative of the family of cyclodiene insecticides (which includes Mirex, aldrin, dieldrin, heptachlor, etc.) synthesized from hexachlorocyclopentadiene. It is the ketone analog of Mirex. Both are moderately soluble in organic solvents, and have low solubilities in water, that of Kepone being (1 to 2 mg/ℓ) when solution pH is less than 6.

Kepone is a white to light-gray or light-brown colored granular solid. Its carbonyl bond and less fully chlorinated structure render it less resistant to chemical and thermal degradation than the related pesticide Mirex. Thermal decomposition begins at about 350°C, becoming rapid at 450 to 500°C. In addition to hexachlorobenzene and hexachlorocyclopentadiene, a third degradation product, which may be octachloroindene (C_9Cl_8), has been observed. When Kepone is exposed to 900°C for approximately 1 sec, decomposition is essentially complete (Carnes, 1977).

Kepone is readily soluble in acetone, lower aliphatic alcohols and some other organic solvents, and somewhat soluble in benzene, toluene and hexane. It is soluble in aqueous sodium hydroxide. Allied Chemical Company data indicate that the solubility is in the range of 1.5 to 2 mg/ℓ (ppm) over the pH range of 4 to 6. In the 9 to 10 pH range, solubility increases to 5 to 70 mg/ℓ (ppm). In 0.001M NaOH (pH 10.9), solubility is 176 mg/ℓ (ppm).

Upon exposure to ordinary temperatures and humidities, the anhydrous compound readily takes up water, and each molecule may contain as much as three water molecules of hydration. The trihydrate, $C_{10}Cl_{10}O.3H_2O$ (9.92% water), appears to be the stable form. However, while the anhydrous form was unsatisfactory in producing dust bases and water dispersible powders because it has a tendency to take up moisture during mixing and milling steps, the trihydrate was considered unsuitable for producing emulsifiable concentrates. The monohydrate (3.54% water) through the dihydrate (6.84% water) were regarded as satisfactory for both uses. The total water specifications for technical Kepone were thus established at 3.5 to 6.0%.

NATURAL PATHWAYS FOR KEPONE MOVEMENT

It has been observed and reported that Kepone resides in the soil, sediments, water and biota of Hopewell and the James River Basin. Much of this contamination has moved from where it was originally deposited. Such translocation appears to continue at the present time and is an important factor in determining the long-term implications of Kepone contamination as well as the ultimate distribution of the pesticide. Consequently, the various pathways by which Kepone moves through the environment must be quantified. These pathways include physical and biological mechanisms functioning in the air and water media as diagrammed in Figure IV.1. Prospective pathways responsible for current Kepone movement patterns are believed to be volatilization, sorption-desorption, plant uptake, bioconcentration and physical movement of Kepone-laden suspended solids. These are discussed individually. Movement of suspended solids is the subject of the sediment transport modeling effort described in Chapter VII.

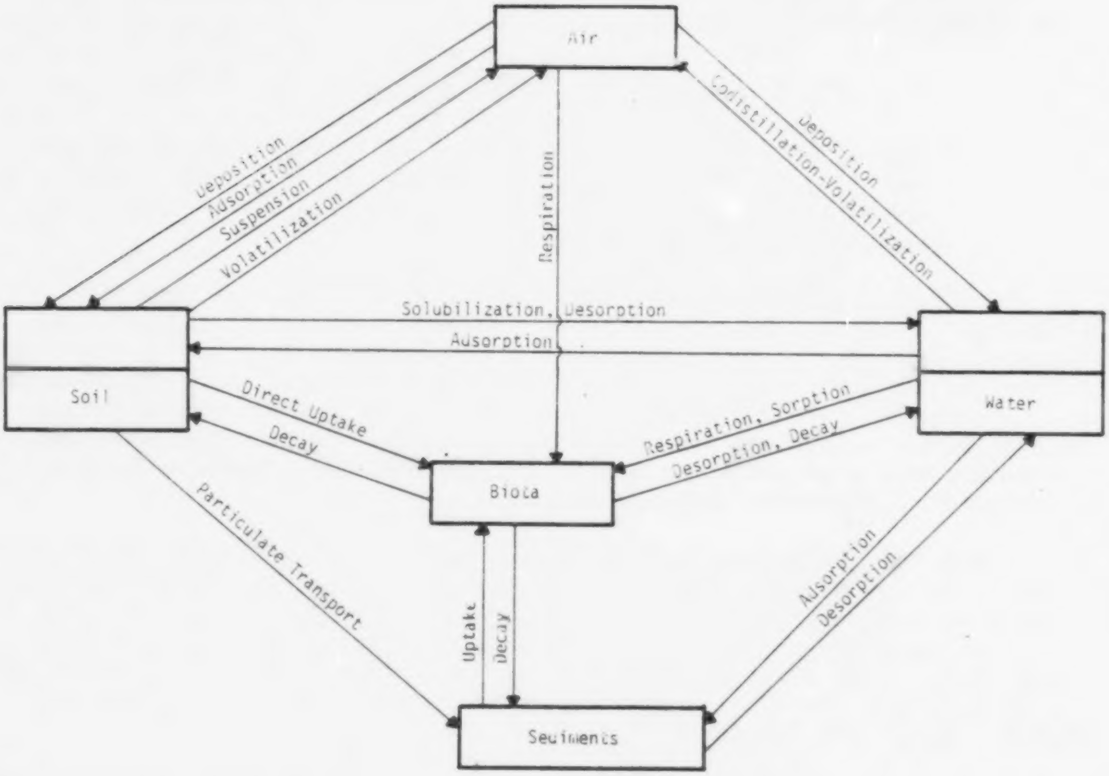
Air
Deposition
Adsorption
Suspension
Volatilization
Respiration
Deposition
Codistillation-Volatilization
Solubilization, Desorption
Adsorption
Soil
Water
Direct Uptake
Decay
Respiration, Sorption
Desorption, Decay
Biota
Particulate Transport
Uptake
Decay
Adsorption
Desorption
Sediments

FIGURE IV.1. Pathways by which Kepone Moves in the Environment

Volatilization

It has been suggested that codistillation of Kepone with water will lead to volatilization of significant portions of the contamination in the James River over time. This projection, based in part on mathematical models which simulate the vaporization process, has been verified in the laboratory for DDT in natural waters (Singmaster and Crosby, 1977). To investigate the potential importance of this mechanism, theoretical calculations based on these models were complemented with laboratory investigations. Laboratory results reveal no significant losses of Kepone by volatilization. However, the theoretical calculations and considerations are discussed because of the importance of this issue. Details are provided in Appendix A.

Results of theoretical calculations suggest losses of 1.34 to 4.92 x 10^{-5} g/hr/m^2 of water surface. Some sense of the magnitude of these rates can be gained by applying them to Bailey Bay.

Bailey Bay encompasses approximately 3.2 x 10^6 m^2 (800 acres). This would extrapolate to losses of:

$$L = (3.2 \times 10^6) \times (2.5 \times 10^{-5}) \text{ g/hr} = 80 \text{ g/hr}$$

That is a large amount of Kepone to be leaving Bailey Bay through the atmosphere. If verified, it suggests that Kepone may be far shorter lived in the river than estimated. The loss ratio is also of sufficient magnitude that it should be measurable in laboratory apparatus if accurate.

Empirical studies have been conducted to substantiate or deny this potential loss mechanism. The first series was conducted at the U.S. EPA Research Laboratory at Gulf Breeze, Florida (Garnas et al., 1977). In both static and continuous flow experiments, it was determined that volatilization did not occur at detectable levels. Labeled ^{14}C-Kepone and sorbent traps were employed to maintain low limits of detection. Hence, if volatilization did occur, it was at extremely low levels and much less significant than predicted by the theoretical calculations.

Additional studies at Battelle supported findings of a lack of volatilization. Plexiglas boxes of both dry Kepone-contaminated sediments and sediments under standing water were exposed to direct sunlight over a 12-week period as described in Chapter X. Activated carbon and synthetic sorbent traps (XAD-2) were placed on flow-through vents (see Figure X.2). After the exposure period, the traps were regenerated with solvent and analyzed for Kepone. In no case was Kepone detected.

There is clearly a conflict between the theoretical data and laboratory observations. Continued persistence of Kepone in the sludge lagoon would tend to support the empirical observation in the laboratory over those stemming from the theory. The anomaly between the two may come from the strong interaction noted between Kepone and particulate matter. Sorption onto particulate matter in the water column is so strong that in most areas dissolved Kepone concentrations are below detectable limits. This could significantly reduce the quantity of Kepone available for evaporation. Regardless of the mechanism involved, data generated in this study suggest that volatilization does not play a major role in the movement of Kepone between segments of the environment.

Sorption - Desorption

Movement between water and soil/sediment systems is largely a function of sorption-desorption mechanisms. Kepone, unlike many chlorinated pesticides, is slightly polar because of the presence of the carbonyl group. This leads to a higher solubility than other chlorinated hydrocarbons. On the other hand, Kepone also has a high affinity for particulate matter as is evidenced by comparison of total and dissolved Kepone levels in James River water grab samples (Table IV.1). Sorption on particulate matter is somewhat analogous to partitioning in an immiscible two-solvent system.

TABLE IV.1. RELATION OF KEPONE CONCENTRATIONS IN WATER AND SUSPENDED SOLIDS IN JAMES RIVER AND BAILEY BAY GRAB SAMPLES (NOTE: SAMPLES WERE HELD FOR TWO WEEKS BEFORE ANALYSIS AND THEREFORE ARE ASSUMED TO HAVE BEEN IN EQUILIBRIUM)

Sample	Kepone Concentration in Water, μg/ℓ-ppb	Kepone Concentration in Suspended Solids, μg/g-ppm
Burwell Bay	<0.06	0.143
Hog Island	<0.006	0.076
	<0.054	0.010
Swann Point	<0.006	0.088
	<0.006	0.068
	<0.006	0.175
	<0.006	0.107
	<0.006	0.060
Windmill Point	<0.006	0.133
Bailey Bay	0.016	0.074
City Point	0.042	0.094
Bailey Creek	0.031	0.46
	0.053	0.077
	0.24	1.38

The organic solute will divide itself between the two phases in a manner reflecting its comparative affinity for each. Hence, a nonpolar organic will accumulate in the lipid fraction of organic solids to a higher concentration than its residual levels in the water column. This also occurs with Kepone. As noted in the discussion of results from analysis of Bailey Bay, Kepone concentrations are correlated with organic content, and always exceed concentrations of dissolved Kepone in the associated waters.

The quantitative aspects of sorption-desorption mechanisms can be predicted using a simple BET-isotherm equation assuming that: (1) only random dispersive and hydrophobic interactions constitute the primary forces controlling the distribution of Kepone between aqueous and suspended phases, and (2) the system is equilibrated at low aqueous concentrations (<10% solution). A detailed discussion of the development can be found in Appendix A. Results obtained by utilizing this approach and available data on Kepone suggest a K value of 0.57 to 1.1×10^5 (partition coefficient 1 to 2×10^{-5}). The partition coefficient employed here is defined as the ratio of concentrations of soluble Kepone in water to concentrations of Kepone on particulate matter. When these values are modified to reflect the effect of particle size and organic content on sorption characteristics, the relation illustrated in Figure IV.2 is obtained.

To supplement theoretical considerations, a limited amount of empirical data were collected on soluble Kepone concentrations and Kepone levels on the particle matrix under equilibrium conditions. Since the results vary with the quality of the water and the nature of the solids both parameters must be selected to be as close to those found in the James River as possible. This was accomplished by taking Kepone-contaminated sediments and equilibrating with James River water. The soluble and particulate Kepone levels were determined as a measure of partitioning. From samples taken in Bailey Bay, Kepone concentrations were 0.074 μg/g (ppm) and 0.016 μg/ℓ (ppb) in suspended solids and water, respectively, yielding a partition coefficient of 2.2×10^{-4}. At City Point on the James River the values were 0.094 μg/g (ppm) in suspended solids and 0.042 μg/ℓ (ppb) in water. The associated partition coefficient was 4.5×10^{-4}. In Bailey Creek, three partition coefficients were determined: 6.8×10^{-5}, 6.9×10^{-4}, and 1.7×10^{-4}. Similar data for samples in the area of the Chickahominy (see Chapter VI) yield a partition coefficient nearly one order of magnitude smaller. This change roughly parallels a trend to smaller average particle size of sediments in that zone (higher clay content) and hence corresponds to predictions based on Figure IV.2 and data given in Appendix A. For the purposes of mathematical modeling described in Chapter VI, a value of 1×10^{-5} was found to be representative of phenomena observed in the James River proper.

Desorption can be influenced by various water quality parameters in the surrounding waters. However, investigations at VIMS (Huggett et al., 1977) have revealed that salinity and temperature have no apparent effect on Kepone partitioning, while the pH of the solutions does. Subsequent investigations at Battelle yielded the leachate levels reported in Table IV.2. The effect of elevated pH levels is quite prominent utilizing the standard elutriate test as described in Chapter X.

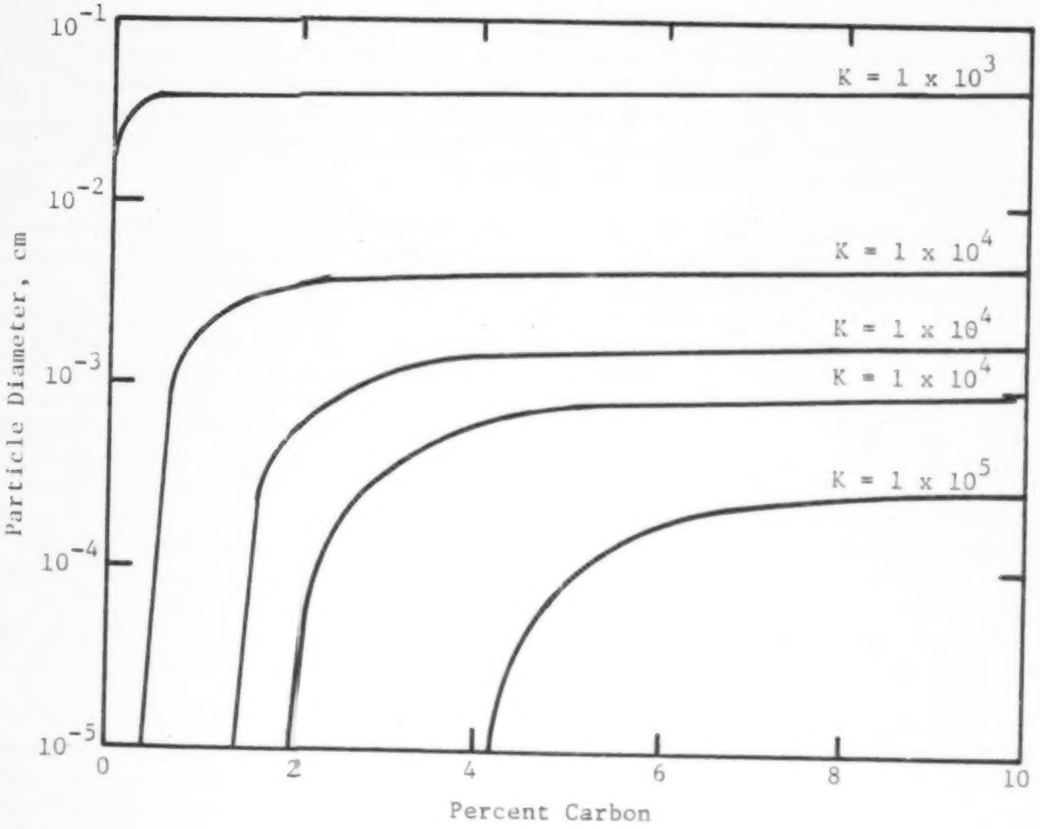

FIGURE IV.2. Plots of K as a Function of Percent Carbon and Particle Diameter

TABLE IV.2. EFFECT OF pH ON KEPONE CONCENTRATIONS IN LEACHATE FROM SEDIMENTS WITH 1 μg/g (ppm) KEPONE

pH	Kepone Concentration (μg/ℓ-ppb) in Leachate
Normal Range for James River	
7.2	0.031
8.5	0.041
Levels Observed in Bailey Creek	
10.5	0.17
12.0	6.84

Researchers at the U.S. EPA Gulf Breeze Laboratory have reported that salinity and aerobicity have no effect on desorption from sediments. Additionally, use of direct light failed to stimulate desorption (Garnas et al., 1977). They have also reported that a given fraction of sorbed Kepone (1 to 5%) does not desorb when contacted with organic solvents, suggesting a fraction of unavailable Kepone in the sediments.

These considerations are very important with respect to Kepone movement in the James River. Due to the marked preference for solids, Kepone will rapidly sorb onto particulate matter in the water and either settle to the bed or move with the suspended solids. Consequently, the key to understanding Kepone movement will rest with understanding the sediment transport mechanisms. This topic is addressed in detail in subsequent sections describing the use of a mathematical model to predict sediment movement in the James River. For the purposes of the model projections, the empirical average value of 1×10^{-4} (Kepone in water to Kepone in sediment) was employed. This is greater partitioning than that calculated from washout studies at Gulf Breeze (relative partition coefficient 10^{-3}). However, the sediment used in these studies averaged only 1.4 to 4.4% organic loss on ignition compared to 6 to 52% loss on ignition noted in Bailey Bay sediments. These lower levels of organic content may dictate a larger partition fraction as is predicted by the theoretical construct. Therefore, the value employed here (1×10^{-4}) reflects sediments with a greater organic content.

Sorption-desorption mechanisms are also important with respect to movement in soils. Storm water percolating through the soil may take up Kepone by dissolving particulate deposits or desorbing Kepone from soil particles. Solutions of Kepone may lose the pesticide through sorption onto soil particles. Hence migration can be attenuated by the soil column. Samples of surface and subsurface soil from the Hopewell area were collected and subjected to a batch sorption test to determine Kepone partitioning. Results are presented in Figure IV.3. The loam soil displayed a higher affinity for Kepone than did the clay loam with a partition coefficient (the ratio of concentration of Kepone in water to concentration of Kepone on soil) of roughly 3×10^{-3} compared to 6×10^{-3} for the clay loam. The loam and clay loam displayed loss on ignition of 4.9 and 3.9%, respectively. These empirical data correspond with a trend to higher partition coefficients with increased organic content. These values are also quite close to the values predicted by the theoretical construct.

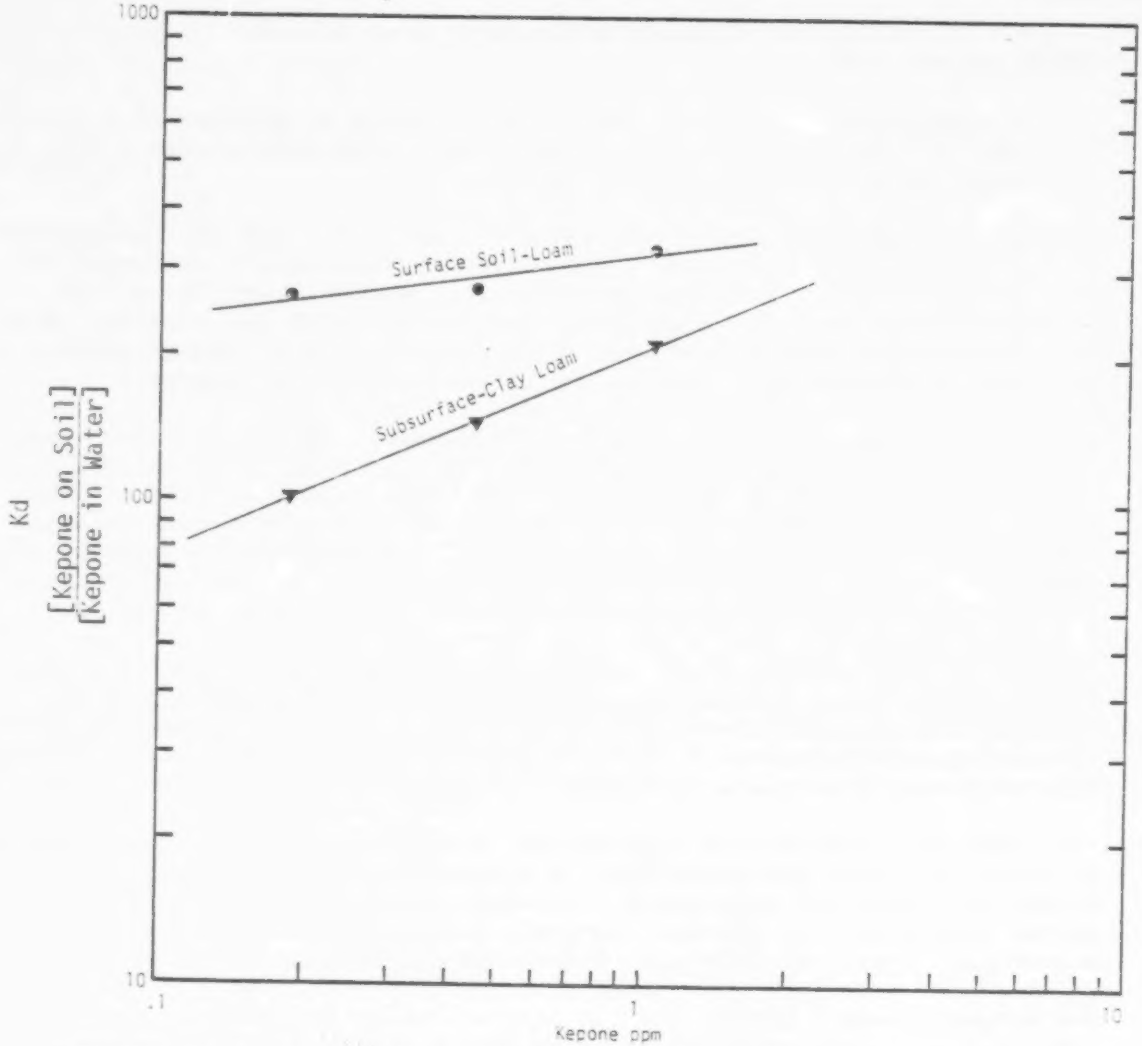

FIGURE IV.3. Relative Partitioning of Kepone in Soil-Water System

BIOLOGICAL TRANSLOCATION

Aquatic Organisms

One means of biological translocation of Kepone involves bioconcentration in aquatic organisms. This topic is discussed in some detail in the section on biological effects (Chapter VIII) and is the subject of comprehensive study at the Gulf Breeze Laboratory.

For reference, the following definitions taken from Kneip and Lauer (1973) are applied:

> Bioconcentration refers to the process by which an organism or a population of many organisms of the same trophic level concentrates a substance directly from the water medium.
>
> Bioaccumulation refers to the process by which an organism concentrates a substance and continues to concentrate it essentially throughout its active metabolic lifetime, such that the "concentration factor," if calculated, would be continuously increasing during its lifetime. Bioaccumulation here is also used to imply concentration through intake of food as opposed to bioconcentration from water and/or sediments.

At the lowest level of the aquatic food chain, algae concentrate Kepone from water, in which Kepone has low solubility. This uptake of Kepone by algae can result in bioaccumulation at higher trophic levels. Recent data from Huggett et al. (1977) reveal average phytoplankton levels in the James River of 1.3 μg/g (ppm) Kepone. Yet Kepone concentrations of 0.35 to 1.0 μg/g (ppm) are also considered sufficient to disrupt or destroy algae, directly affecting productivity at higher food chain levels (Walsh et al., 1977).

At the next trophic level, aquatic invertebrates are capable of bioconcentrating Kepone to high levels. Bahner et al. (1977) reported high bioconcentration factors for the opossum shrimp (mysid), grass shrimp and oyster from Kepone concentrations as low as 0.023 μg/ℓ (ppb) in sea water. Depuration of Kepone from oysters in Kepone-free water was rapid (35% in 24 hr).

Laboratory exposures of fish species to Kepone showed the insecticide to be bioconcentrative and persistent. Sheepshead minnows bioconcentrated Kepone to excessively high levels. Juvenile progeny, hatched and grown in Kepone-free water from contaminated adult fish, contained Kepone. Spot, a commercially important food fish, bioconcentrated Kepone from seawater containing 0.029 μg/ℓ (ppb) to a level of approximately 0.21 mg/ℓ (ppm). One of the largest Kepone reserves (22%) in absolute weight was found in the edible portion of the contaminated fish. Fish have slow depuration rates compared to oysters with only 30 to 50% of the accumulated Kepone lost after 3 or more weeks in Kepone-free water (Bahner et al., 1977).

Accumulation, transfer and loss of Kepone in estuarine food chains have been studied in laboratory bioassays (see Table IV.3). Kepone was found to be bioconcentrated from concentrations as low as 0.023 μg/ℓ (ppb) in sea water by oysters, mysids, grass shrimp, sheepshead minnows and spot. Bioaccumulation also occurs and is relatively important for species such as the blue crab. In general, uptake is believed to include all three routes: food, water, and sediments. At this time it is not known which is the predominant route for species in the river. In laboratory studies, the water route is predominant for fin and most shell fishes. The food route predominated for blue crab and spot. Sediments were most important for polychaete worms and fiddler crabs (food was also important for the crabs) (Bahner et al., 1977).

TABLE IV.3. BIOCONCENTRATION FACTORS REPORTED FOR VARIOUS SPECIES*

Species	Bioconcentration Factor	Kepone Concentration in Water, cycle-ppb	Reference
Algae	80 - 520	100	Walsh, 1977
Grass Shrimp	698	12 - 121	Schimmel and Wilson, 1977
	5,127 - 11,425	0.023 - 0.4	Bahner et al., 1977
Mysid	5,962 - 13,473	0.026 - 0.41	Bahner et al., 1977
Oyster	9,354 - 9,278	0.03 - 0.39	Bahner et al., 1977
Blue Crab	8.1	110 - 210	Schimmel and Wilson, 1977
Sheepshead Minnow	1,548	7.1 - 78.5	Schimmel and Wilson 1977
	7,115	0.05	Bahner et al., 1977
Adult	5,200	0.05 - 24.	Hansen et al., 1977
Juveniles	7,200	0.08 - 33	Hansen et al., 1977
Spot	1,221	1.15 - 15.9	Schimmel and Wilson, 1977
	3,217 - 2,340	0.029 - 0.40	Bahner et al., 1977

Bioaccumulation

Food Chain	Bioaccumulation Factor	Reference
Algae→Oyster	2.1	Bahner et al., 1977
Water→Algae→Oyster	0.007	Bahner et al., 1977
Brine Shrimp→Myrids	0.53	Bahner et al., 1977
Mysid→Spot	0.85	Bahner et al., 1977
Brine Shrimp→Mysid→Spot	10.5	Bahner et al., 1977

---

* Additional details and data can be found in Chapter VIII.

Oysters that were fed the green alga Chlorococcum, containing an average of 34 μg/g (ppm) Kepone, bioaccumulated 0.21 μg/g (ppm) Kepone (wet tissue) in 14 days. In Kepone-free water, they depurated Kepone to below detectable concentrations within 10 days. Thus, the transfer and retention of Kepone from algae by oysters is relatively inefficient (Bahner et al., 1977).

Spot accumulated Kepone when fed live mysids that had grazed on Kepone-laden brine shrimp. The efficiency of the transfer of Kepone between fish food organisms and fish results in a potential transfer of the pesticide to humans via the consumption of fish, particularly spot (Bahner et al., 1977).

Extensive studies on bioconcentration and accumulation have been conducted by the Gulf Breeze Laboratory. More complete and detailed coverage of the topics briefly mentioned above may be found in the Gulf Breeze Laboratory reports. A summary of reported bioconcentration values can be found in Table IV.3.

Avian Organisms

Little work has been directed to delineation of subsequent bioaccumulation in avian predators. However, a memo from the U.S. Fish and Wildlife Services, Patuxent Wildlife Research Center discusses preliminary findings from random samples, which suggest that accumulation is occurring, as outlined in the following quote:

> "Following the receipt of information on contamination of the James River in Virginia by Kepone, the chemists in the Environmental Residue Chemistry Project at Patuxent Wildlife Research Center began to develop a suitable analytical method for Kepone in wildlife samples. After the development of the method they began to analyze liver and/or carcass samples from 17 bald eagles that were found dead in Maryland and Virginia between 1966 and 1976. Tissues of bald eagles were selected because these birds are at the top of aquatic and terrestrial food chains and would be expected to be exposed to Kepone in areas where it has contaminated the environment.
>
> The results of the Kepone analyses of bald eagle tissues are presented in [Table IV.4a]. Three birds appear to have experienced high environmental exposure to Kepone: an immature eagle from Warsaw, Virginia, an adult from Spotsylvania County, Virginia, and an adult from Richmond County, Virginia. Most birds from Maryland, at greater distances from the source of contamination, contained relatively low levels of Kepone in their tissues. Single eagles from Oklahoma and Minnesota contained no detectable Kepone in their livers or carcasses.
>
> Three bald eagle eggs from different nests on the Virginia shore of the estuarine portion of the Potomac River, collected in 1976, contained 0.14 to 0.19 ppm (wet weight) of Kepone.

TABLE IV.4a. KEPONE IN MARYLAND AND VIRGINIA BALD EAGLES

Source	Date	Age and Sex	ppm Kepone, wet weight Liver	ppm Kepone, wet weight Carcass
Calvert County, MD	10/66	I -*	na†	nd‡
Allegany County, MD	12/68	I F	na	nd
Newport News, VA	1/70	I M	12.	nd
Winchester, VA	9/72	I F	nd	nd
Virginia Beach, VA	10/74	I F	0.02	nd
Warsaw, VA	3/75	I M	130.	44.
Vienna, MD	2/68	A F	0.2	nd
Accokeek, MD	5/70	A F	16.	2.2
Spotsylvania County, VA	3/72	A F	83.	21.
Templeman's, Westmoreland County, VA	1/73	A F	0.13	nd
Deale, MD	7/73	A M	1.3	0.1
Queen Anne County, MD	1/74	A M	1.3	nd
Phillips Landing, Richmond County, VA	4/74	A M	50.	19.
Beach Creek, Rapahannock River, VA	9/74	A M	3.4	0.24
Chestertown, MD	1/75	A F	0.76	nd
Springfield, VA	3/74	- -	1.3	nd
Solomons Island, MD	1/76	- -	1.6	0.24

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* - = unknown
† na = not analyzed
‡ nd = not detected
I = immature
A = adult

A series of osprey eggs from 16 nests in Virginia were collected during the 1976 reproductive season by Dr. Mitchell Byrd of the College of William and Mary. Ospreys almost exclusively prey on fish and therefore would be expected to be exposed to Kepone in areas where it has contaminated the aquatic environment. These eggs were analyzed for Kepone. Data are presented in [Table IV.4b]. Although there was no clear relationship between residue levels of Kepone in these eggs and the distance of their source nests from the mouth of the James River, there was a slight tendency toward lower levels in the eggs from nests at greater distances. Eggs from one nest in New York, two nests in Maine and three in Montana contained no detectable residues of Kepone.

No statements can be made at this time on the possible biological significance of these residue levels of Kepone on reproductive success or survival. Published information on experimental studies showing the effects of Kepone on birds has provided little useful information for the interpretation of residue levels."

TABLE IV.4b. KEPONE RESIDUES IN OSPREY EGGS AT INCREASING DISTANCES FROM THE MOUTH OF THE JAMES RIVER, VIRGINIA

	ppm Kepone (wet weight)		
Collection Area	n	$\overline{X}$	Range
York River	1	1.1	--
Mockhorn Bay, Atlantic Coast, Eastern Shore	1	0.49	--
Mouth of Rappahannock River and adjacent areas	5	0.69	0.06-1.5
Fleets Bay	3	0.37	0.05-0.90
Great Wicomico River	3	0.37	0.23-0.57
Rappahannock River, upstream from mouth	3	0.20	0.09-0.27

Data from Kepone content in other avian species have been reported by Huggett. These are summarized in Table IV.5 (U.S. Fish and Wildlife Service, 1977).

TABLE IV.5. KEPONE RESIDUALS IN AVIAN SPECIES 1976-1977 (U.S. FISH AND WILDLIFE SERVICE, 1977)

Species	Location	Organ	Number of Samples	Average Kepone Concentration (ppm)	Standard Deviation
Pintail	Upper Brandon	Fat and liver	1	< 0.02	---
Mallard	Upper Brandon	Fat	2	0.16	---
		Liver	2	1.28	0.45
Mallard	Hog Island	Liver	7	0.36	0.24
Mallard	Presquile	Liver	6	0.19	0.15
Mallard	Near Brandon	Gizzard	4	< 0.02	--
Black Duck	Hog Island	Liver	4	1.25	0.55
Black Duck	Presquile	Liver	6	0.12*	0.10
Wood Duck	Presquile	Liver	6	0.04†	0.10
Hooded Merganser	Hog Island	Liver	2	2.70	0.28
Red Head (found dead)	York River	Liver	2	0.043*	0.06
Coot	Hog Island	Liver	4	0.53	0.49
Coot	Presquile	Liver	6	0.32	0.15
Herring Gull	Hog Island	Liver	1	3.7	---
Herring Gull	Presquile	Liver	2	1.38	0.60
Great Blue Herron	Hog Island	Liver	4	13.23	15.84
Great Blue Herron	Eastern Shore	Liver	1	1.3	---
Canada Goose	Hog Island	Liver	6	0.003‡	0.01
Canada Goose	Presquile	Liver	6	0.02	0.02

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* One Sample <0.02 ppm, calculated as 0
† Five Samples <0.02 ppm, calculated as 0
‡ Two Samples <0.02 ppm, calculated as 0

Although the above data are far from comprehensive or complete, they point out several key findings. First, it is important that Kepone was found in eagles taken from Newport News, Spotsylvania County and Templemans (Westmoreland County) prior to the start up of the Life Science Products Company facility. Hence, while little is known of Allied Chemical's contributions to environmental Kepone levels compared to those of Life Science Products, they were detectable and significant. This is especially true in light of the Kepone concentration in the liver of the Spotsylvania County eagle (83 μg/g-ppm).

Secondly, since some avian predators have accumulated high concentrations of Kepone, it is reasonable to assume that the vast majority of this has been taken in through consumption of contaminated fish. Hence, bioaccumulation of Kepone is a factor with birds. Furthermore, osprey egg data would tend to indicate subsequent transfer to offspring.

Uptake in Plants

Persistent contaminants move through the environment via a number of physical, chemical and biological mechanisms depending both on their intrinsic properties and the extrinsic characteristics of the system. These mechanisms may serve both to disperse the contaminant to safer levels or to concentrate it in such a way that it poses a greater threat to organisms. The concentration is true of materials such as heavy metals which can be translocated from the soil or water and accumulated in plants. Consequently, when considering the fate and effects of contaminants the degree to which they are picked up by plants and concentrated in the edible portions must be evaluated. This is particularly true of contaminants known to reside in sediments.

The question of uptake and concentration of Kepone therefore concerns two factors. First, large quantities of Kepone were spread about the Hopewell area and may subsequently be available for uptake by plants grown for human or livestock consumption. Secondly, much of the Kepone currently resides in sediments which, if dredged, may be placed in large spoil banks where growth of plants is inevitable and often encouraged.

Little has been reported on the interactions of Kepone and plants. The scarce data that do exist were generated during work with the related compound Mirex. Mirex was found to cause significant growth reduction as concentrations approached 0.15 μg/g (ppm) in soil for Johnson and annual rye grass, 0.3 μg/g (ppm) for tall fescue and alfalfa, and 0.70 μg/g (ppm) for alsike clover. Uptake and accumulation was directly related to the concentration of Mirex in the rooting medium. Similar uptake preferences were found in soybean, garden bean, sorghum, and wheat seedlings (de La Cruz and Rajanna, 1975).

In studies with peas and beans, the plants were found to extract Mirex from contaminated water. Resulting concentrations in roots exceeded those in water by factors of 6 to 10. However, concentrations in shoots were always less than those in the original water (Mehendale et al., 1972). No further data were given to determine if uptake was part of the plants' metabolism or a function of adsorption on the roots' surface.

To provide sufficient data to determine if uptake by plants will play a significant role in the fate and effects of Kepone residuals in the Hopewell area, a laboratory study was conducted using Kepone-spiked and naturally contaminated soils and sediments.

A modified Neubauer Technique (Bear, 1948) was employed for the study using 200 gram samples of Ritzville sandy loam soil. One sample set was spiked with Kepone and a second with Kepone-contaminated sediments. Spiking was accomplished by dissolving technical-grade Kepone in 90% ethanol. The resulting solution was pipetted onto the soil samples to yield batches containing 0.1 μg Kepone/g soil (ppm), 1.0 μg Kepone/g soil (ppm), and 10.0 μg Kepone/g soil (ppm). Oven-dried (105°, 24 hr) sediments from Bailey Bay containing approximately 1 μg Kepone/g (ppm) were mixed at a ratio of 1:10 with soil to form a fourth set of media. Samples were placed in an oven set at 60°C and dried for 16 hr prior to potting.

Each of the four sets of media was divided into five replicates and placed in 473 ml (1 pint) cartons lined with plastic. Soil was watered with 50 ml of water per pot, planted with 100 barley seeds, and the surface covered with 45 g (0.099 lb) of coarse sand. All pots were placed in a controlled environmental growth chamber set at 16 hr of light and 8 hr of darkness per day. Temperature was maintained at 25°C during the day and 19°C at night. After germination, pots were watered daily until harvested after 14 days. When harvested, plants were clipped just above the soil surface, placed in glass beakers, and oven dried at 50°C for 48 hr. A regrowth crop was then grown under the same conditions.

Results of the two cycles of barley growth in contaminated soils are presented in Table IV.6. In general, all plants grew normally and no toxicity symptoms were observed. All samples were below detectable levels for Kepone except the second cutting on pot numbers 4 and 15. These were believed to have experienced contamination from the soil media after the first cutting and not to reflect uptake. With or without these two values, no apparent uptake pattern was evidenced. It would appear that plants will not translocate Kepone into their shoots, stems or leafy parts. The high yield in pots 16 to 20 for the second cutting is believed to reflect nitrogen and other nutrients in the sediments not present in the spiked soil samples since Bailey Bay sediments are high in organic nitrogen content.

The above finding agrees with other ongoing work. Dr. Robert Huggett at the Virginia Institute of Marine Science notes that work with rooted aquatic plants shows no uptake to the stem or leafy parts. Similarly, Mr. Paul Griffen with General Electric finds no uptake of another polychlorinated hydrocarbon, PCBs, in terrestrial plants. Some PCB content is found in root tissues, but this is believed to reflect physical sorption and not systemic uptake.

Based on limited literature reports and ongoing studies, it is concluded that Kepone is not amenable to plant uptake from soil or sediments. Hence, it is unlikely that man or other species are threatened by Kepone as a result of consumption of crops or wild fauna from the Hopewell area. Some residues may be consumed as a result of foliar depositions or sorption on root stocks, but potential for deposition diminishes with time and sorption is unlikely unless high concentrations of Kepone in soil are found below the soils surface. This could be of some concern if root crops were grown in contaminated dredge spoils.

TABLE IV.6. GROWTH OF BARLEY IN KEPONE CONTAMINATED SEDIMENTS

Sample No.	Conditions	First Cutting Oven Dried Net Weight, g	Kepone Content First Cutting, μg/g (ppm)	Second Cutting Oven Dried Net Weight, g	Kepone Content Second Cutting, μg/g (ppm)
1	0.1 μg Kepone/g soil	1.094	<0.04	0.668	<0.04
2	0.1 μg Kepone/g soil	0.934	<0.04	0.770	<0.05
3	0.1 μg Kepone/g soil	1.371	<0.03	1.034	<0.02
4	0.1 μg Kepone/g soil	1.351	<0.03	0.886	0.17
5	0.1 μg Kepone/g soil	1.299	<0.03	0.590	<0.03
Max Potential Ave		1.210	<0.03	0.790	<0.06
6	1.0 μg Kepone/g soil	0.377*	<0.01	0.713	<0.05
7	1.0 μg Kepone/g soil	1.411	<0.03	1.138	<0.03
8	1.0 μg Kepone/g soil	1.388	<0.03	0.589	<0.06
9	1.0 μg Kepone/g soil	0.752	<0.05	0.707	<0.06
10	1.0 μg Kepone/g soil	1.417	<0.02	0.691	<0.06
Max Potential Ave		1.242†	<0.03	0.768	<0.05
11	10 μg Kepone/g soil	1.350	<0.03	0.970	<0.02
12	10 μg Kepone/g soil	1.020	<0.02	0.548	<0.07
13	10 μg Kepone/g soil	1.264	<0.03	0.944	<0.04
14	10 μg Kepone/g soil	0.946	<0.04	0.790	<0.05
15	10 μg Kepone/g soil	0.995	<0.04	0.894	0.11
Max Potential Ave		1.115	<0.03	0.829	<0.06
16	1:10 Contaminated Sediments:Soil	1.400	<0.03	1.282	<0.02
17	1:10 Contaminated Sediments:Soil	1.059	<0.04	1.200	<0.02
18	1:10 Contaminated Sediments:Soil	1.263	<0.03	1.127	<0.02
19	1:10 Contaminated Sediments:Soil	1.397	<0.04	1.261	<0.02
20	1:10 Contaminated Sediments:Soil	1.125	<0.03	1.410	<0.02
Max Potential Ave		1.249	<0.03	1.256	<0.02

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* Sample No. 6 was over-watered and had a subsequent low germination rate, growth of germanated plants was normal

† Excludes No. 6

These findings do not address the question of Kepone pickup from contaminated water. Recent work by numerous investigators has shown that plants such as water hyacinths and bullrushes are capable of taking up organic material like PCBs from contaminated water. This is believed to involve a surface sorption mechanism rather than uptake and therefore differs significantly from uptake from soil or sediments.

Biological Transport

As Kepone is concentrated in mobile biota, it physically moves in the water system along with the host. Kepone is transported via two biological pathways in the James River. One pathway for the removal of Kepone is via the fish biomass taken by the sport and commercial fisheries. A second pathway for removal is represented by the migration of juvenile and adult organisms out of the James River. The magnitude of the amount of Kepone transported via these mechanisms must be determined to fully assess the many proposed actions for mitigating the Kepone contamination of the James River system.

An accurate determination of the amount of Kepone that is removed via these pathways would require detailed information and estimates on the many biological and chemical components of the James River system. The two critical parameters for each pathway are the organism biomass and its level of Kepone contamination. Additional measurements of uptake and depuration rates are needed for those species that are transient with the James River. Although many of these data are currently unavailable, it is possible to evaluate the relative magnitude of the biologically transported Kepone.

Of the many biological components, the best available data are for the commercial catch pathways. The application and interpretation of these data depends on several qualitative assumptions and limitations. However, since the river has been closed to the taking of several of the most important species (those with the high Kepone body burdens), this mechanism of removal does not currently function to any significant extent.

Partial data are available for the second pathway, the migration of adult and juvenile fish out of the James River and the associated transport of Kepone. A quantitative assessment of this Kepone transport pathway would require population biomass estimates and Kepone concentrations when these organisms leave the estuary. Little of this information exists nor is it likely to become available in the foreseeable future. The data that are available are based on relative indices of population size and therefore can only be utilized in a qualitative manner.

Two approaches to estimating population biomass are reported in this chapter. The first is based on the catch-per-unit-effort fishing data and the second on an extrapolation from the commercial catch data. While the results are qualitative, they can be used to indicate the order of magnitude of Kepone potentially transported via this pathway.

The catch-per-unit-effort approach is taken from the work of VIMS and the data were supplied by Dr. Michael Bender for summer and winter surveys. The application of these data to estimating the Kepone transport requires the following assumptions: (1) all of the migratory fish populations that were present during the survey leave the system, and (2) these fish are in the James River long enough to accumulate equilibrium levels of Kepone where depuration just cancels further uptake. The estimates of the biomass and Kepone transported in the major species is present in Table IV.7. As can be seen from the total, the magnitude of the Kepone transported is small. The average estimate is 72 kg (158 lb) and the maximum estimate is 225 kg (494 lb). When an estimate is made based on the total summer biomass and an average of 1 μg/g (ppm) Kepone, the total is only 165 kg (363 lb). These estimates may be low in that they assume 100% efficiency in the trawl operation.

The result of the efforts to evaluate the biological transport of Kepone is the highly qualitative conclusion that at most only a few hundred pounds can be expected to be removed annually. As discussed in previous chapters, the maximum tissue concentration that has been observed in living organisms is in the range of 1 to 8 μg/g (ppm). Despite the acknowledged limitations of the population biomass estimates within the various components, it appears reasonable to conclude that the total biomass does not exceed a few hundreds of millions of kilograms. Thus, it is projected that the total amount of Kepone in the James River will decrease by no more than 100 kg per year as a result of biological transport.

DEGRADATION PROCESSES

Biochemical Oxidation

Little has been reported on the possible degradation of Kepone in the environment by microorganisms. Data submitted by Allied Chemical Company showed essentially no decline in soil concentration after 154 days (EPA, 1976).

Garnas et al. (1977) have reported no degradation in model ecosystems investigations using James River sediments and artificially contaminated sediments from unaffected areas. Similarly, natural cores from Bailey Bay and artificially contaminated cores from above Richmond have shown no measurable Kepone degradation in Battelle laboratory studies. These efforts are described in Appendix L.

Photochemical Degradation

Little published work is available on photodegradation of Kepone. Garnas et al. (1977) have reported no measurable effects of irradiation on Kepone losses from water-sediment systems. More quantitative data have been reported on Mirex by Gibson et al. (1972), and Alley et al. (1973) and (1974).

TABLE IV.7. POTENTIAL EXPORT OF KEPONE FROM THE JAMES RIVER VIA MIGRATING STOCKS

Species	Concentration, μg/g-ppm*		CPUE, kg	Source	Catch†	Kepone, kg	
	Maximum	Average				Average	Maximum
Summer Flounder	1.53	1.40	7.4×10^{6} 3.5×10^{4}	VIMS-Summer VIMS-Winter		10.3	11.3
Atlantic Croaker	2.95	0.58	2.5×10^{7} 1.4×10^{5}	VIMS-Summer VIMS-Winter		14.5	74.3
Blueback Herring	1.20	0.08	5.9×10^{4} 4.3×10^{3}	VIMS-Summer VIMS-Winter		-	-
Hickory Shad	0.19	0.14	5.7×10^{2}	VIMS-Winter		-	-
American Shad	0.6	0.05	4.6×10^{3}	VIMS-Winter		-	-
Striped Bass	3.8	0.36	5.4×10^{4} 4.0×10^{2}	VIMS-Summer VIMS-Winter		-	0.2
White Perch	8.0	2.07	2.2×10^{6} 4.5×10^{3}	VIMS-Summer VIMS-Winter		4.5	17.6
Spot	1.5	0.47	6.3×10^{7} 5.3×10^{4}	VIMS-Summer VIMS-Winter		29.7	95.4
Atlantic Menhaden		0.16	1.2×10^{5} 1.6×10^{5}	VIMS-Summer VIMS-Winter		-	-
Gizzard Shad	1.25	0.65	5.0×10^{3}	VIMS-Winter		-	-
American Eel	6.1	1.50	9.2×10^{5} 2.6×10^{4}	VIMS-Summer VIMS-Winter		1.4	5.6
Bay Anchovy	0.59	0.25	1.9×10^{7} 2.8×10^{4}	VIMS-Summer VIMS-Winter		4.75	11.2
Grey Trout	0.31	0.24	10.3×10^{6}	VIMS-Summer		2.5	3.2
Bluefish	2.44	0.86	1.5×10^{6}	VIMS-Summer		1.3	3.66
Bluecrab		0.50‡			5.3×10^{6}	2.7	2.7
					Total	72	225
Total Species		1	1.65×10^{8}	VIMS-Summer		165	

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* Concentrations based on (VIMS computer printout reference)

† Assumed that catch represented 10% of total population source

‡ Average of male and female (sex ratio 1:1)

UV radiation from sunlight or sunlamp caused rapid decomposition of Mirex in amines, but no reaction could be detected under similar conditions when the solvent was cyclohexane. The enhancement is attributed to a charge transfer complex between the amine and Mirex. A series of 12-wk exposure tests with Kepone at Battelle produced no measurable photodecomposition except for cases where amine solutions were introduced to the system. Details can be found in Chapter X.

APPRAISAL OF KEPONE MOVEMENT AND PERSISTENCE

From the data in the preceding sections on movement and degradation of Kepone, several conclusions can be drawn with respect to its persistence in the various environmental sectors. In general, Kepone levels in water and soil will not decrease to any great extent as a result of volatilization. The tendency to tightly bond to soil-sediment particles through sorption overrides co-distillation mechanisms otherwise active in aqueous solutions. While no quantitative data have been developed to identify appropriate modifications for theoretical models on vapor losses, it would appear that the affinity between Kepone and particulate matter acts like an effective increase in solubility. In this manner, the Kepone does not display the aversion for water that its actual solubility would suggest.

Sorption-desorption mechanisms play a major role in determining the movement of Kepone in the environment. For example, the vast majority of all environmental Kepone residuals are attached to soil or sediment surfaces as sorbates. An extensive effort to project the distribution and movement of Kepone-laden suspended sediments and bed load in the James River is described in detail in Chapter VII.

Movement of Kepone into the biological segments of the environment is largely a function of bioconcentration from water and bioaccumulation in food webs. Translocation from soil and sediments by plants has not been demonstrated. Animals take up Kepone from water, food, and sediments depending on species and environmental conditions. Blue crabs and avian predators are the most notable species to take up Kepone from sediments and food. It is the bioconcentration pathway from water that has caused the major economic dislocation on the James River--closure of commercial fisheries because Kepone concentrations are in excess of the FDA action levels. Bioconcentration followed by migration to the ocean with subsequent depuration is a pathway for the elimination of Kepone from the James River. It is estimated that total amounts of Kepone involved may be as much as 100 kg (220 lb) Kepone.

It has also been observed that no significant degradation, either biochemical or photochemical, occurs over the short term. Consequently, total Kepone residuals in the environment can be expected to remain relatively constant while their disposition will reflect the natural movement of soil and sediment particles upon which the Kepone is sorbed. Any measures directed to mitigation of the contamination must therefore address the soils and sediments of affected areas.

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CHAPTER V - ANALYSIS OF CURRENT KEPONE DISTRIBUTION

SUMMARY

Content

Chapter V presents the results of sampling for Kepone residuals in the Hopewell, Virginia area. More than 900 samples were collected in order to establish the distribution of Kepone in the environment and to identify potential sources of continuing contamination to the James River system. The first part of the chapter describes the field sampling techniques, as well as the analytical methods utilized for Kepone detection in the lab. Next, a description of the sampling program is given showing the location from which the various types of environmental samples were collected. Finally, the results of Kepone analysis of the samples are presented along with a discussion of their implications.

Findings

- Use of a toluene:ethyl acetate solvent system for Kepone analysis eliminates extract cleanup steps for the majority of Hopewell environmental samples.
- An estimated 540 kg (1200 lb) of Kepone reside in the sediments underlying Bailey Bay and Bailey Creek.
- The most heavily contaminated bottom sediments of Bailey Bay display Kepone concentrations peaking at depths of 10 to 20 cm.
- Highest Kepone levels in Bailey Bay occur at the mouth of Bailey Creek, with elevated levels continuing in conjunction with the flow pattern of creek water through the Bay.
- Surface soil samples from Hopewell contain Kepone concentrations ranging from several hundred μg/g (ppm) in the area adjacent to the former Life Science Products (LSP) plant to 0.1 μg/g (ppm) in the outskirts of town.
- Sampling results show little downward movement of Kepone through the soil column, with concentrations in the top 1-in. layer generally a full order of magnitude (10-fold) greater than Kepone levels in the second inch of soil.
- The current inventory of Kepone in Hopewell soils resulting from atmospheric fallout during production periods totals between 45 to 450 kg (100 to 1000 lb).
- Surface runoff translocates an estimated 60 to 70 g/day of Kepone from Hopewell soils to the James River system during average periods of rainfall.

- Highest levels of Kepone in surface runoff were detected in the vicinity of the LSP site, ranging from 10 to 700 μg/ℓ (ppb).

- No Kepone was detected in shallow ground-water samples from three wells in the LSP neighborhood.

- Detectable levels of Kepone were found in shallow ground-water wells at the Hopewell landfill, at the site of the Kepone/sludge disposal lagoon, and at a location east of the Hopewell sewage treatment plant. Measured concentrations of Kepone at these wells were 0.24, 0.81, and 0.08 μg/ℓ (ppb), respectively.

- Over a 5-month sampling period, two ground-water seeps from the bank below the Kepone/sludge disposal lagoon contained between 9.6 and 361 μg/ℓ (ppb) Kepone.

- The concentration of Kepone in the Hopewell domestic water supply system is below a detectable limit of 0.02 μg/ℓ (ppb).

- The highest Kepone concentration in an environmental sample, 35,163 μg/g (ppm), was found in marsh sediment adjacent to the southeastern portion of the Hopewell landfill.

- Kepone levels in the top 4 in. of this marsh average 12,200 μg/g (ppm) and account for approximately 1,400 kg (3,100 lb) of the chemical in a 1000 m^2 (0.25 acre) area.

- Analysis of samples from the Pebbled Ammonium Nitrate plant site identified Kepone residuals to depths of 40 ft, comprising an estimated inventory of 100 kg (220 lb) of Kepone.

- An average of 6 g/day of Kepone exit the Hopewell primary sewage treatment plant (STP) in its effluent.

- Continuing Kepone levels in the plant effluent are fed by storm runoff originating in the Life Science neighborhood, by supernatant drawoff from the STP holding tank, and by inflows from the residential sanitary sewer lines.

- The amount of Kepone residuals persisting in the Hopewell sewer system and STP is estimated to be less than 23 kg (50 lb).

- Approximately 100 kg (220 lb) of Kepone are present in the Kepone/sludge disposal lagoon.

- An estimated 9000 kg (20,000 lb) of Kepone reside in the top foot of sediment underlying the James River.

INTRODUCTION

In April 1977, the Environmental Protection Agency Kepone Migration Feasibility Project initiated funded support studies with the Pacific Northwest Laboratory (operated by Battelle Memorial Institute), the Corps of Engineers, the EPA Environmental Research Laboratory at Gulf Breeze, and the Virginia Institute of Marine Science. One aspect of this research involved a field sampling program designed to establish the extent of Kepone deposition in and around the city of Hopewell. Emphasis was placed on identifying specific areas of high Kepone concentration which could potentially serve as continuing sources of contamination to the James River system. Details of the sampling program and subsequent evaluations are given in the following sections.

FIELD STUDY METHODS

The physical-chemical properties of Kepone suggest that the soil and sediment sectors of the environment contain the majority of Kepone residuals. Water serves as the major medium of transfer through transport of contaminated particulates and dispersion of dissolved Kepone. Consequently, sampling included water along with sediment and soils. Sample sites were divided between two geographical zones: (1) Hopewell and the surrounding areas and (2) Bailey Bay.

The Hopewell Area

Extensive sampling was undertaken within the city of Hopewell in order to gather clues concerning the extent that atmospheric, hydrologic, chemical, biological, and human transport mechanisms have dispersed the Kepone. A variety of samples were collected to determine where significant deposits of the chemical reside and how such deposits might find their way into the James River system (Figure V.1). Samples collected include:

- ground water from wells and springs
- streamflow and rainfall runoff
- soils
- water and solids from the city's sewer lines and sewage treatment plant
- sludge and supernatant from the Kepone lagoon

Ground water was collected from monitoring wells in Hopewell maintained by the State Water Control Board, from nearby private wells, and from seeps flowing from the bank below the area of the Kepone lagoon into Bailey Creek. Surface water samples were drawn from several streams around Hopewell.

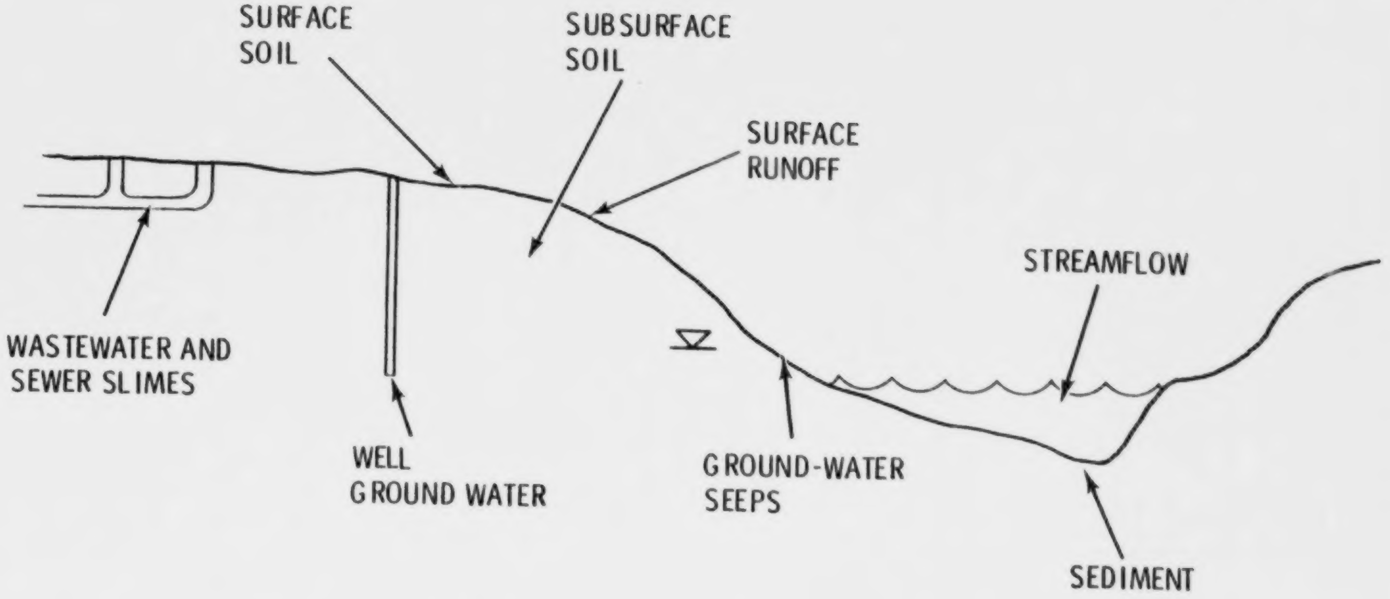
SURFACE
SOIL
SUBSURFACE
SOIL
SURFACE
RUNOFF
STREAMFLOW
WASTEWATER AND
SEWER SLIMES
WELL
GROUND WATER
GROUND-WATER
SEEPS
SEDIMENT

FIGURE V.1. Schematic Summary of Environmental Sample Types

Samples were generally collected downstream of suspected areas of contamination as well as from upstream sites to serve as control points. When possible, two samples were taken at each site, one during a dry period and the other shortly after a significant rainfall. In addition, overland runoff samples were collected around the city during and immediately following rainstorms. Samples of soil were also taken from several locations around Hopewell, with emphasis on the area around the Life Science Products site. The Hopewell primary sewage treatment plant provided samples of sewage influent and effluent. Following analysis of these samples, a program was established to sample slime and sewage from pump stations and manholes as well. Samples at the Pebbled Ammonium Nitrate plant site and landfill were dictated by historical data on disposal sites and topography.

Bailey Bay and its Tributaries

The main component of the Bailey Bay sampling program was the collection of core samples of bottom sediment. Cores were obtained from all parts of the Bay and analyzed for Kepone content. These results were used to establish the present distribution of Kepone throughout the Bay, including its vertical profile. Cores were also collected from Bailey Creek, Poythress Run, Gravelly Run, Cattail Creek, and the western crescent of Tar Bay. In addition, selected cores underwent heavy-metal detection and broad spectrum organic analyses. The final component of the Bailey Bay sampling plan involved collection of water samples, and particle size distribution evaluations.

In the following sections, the procedures used in the overall sampling and analysis program are explained. A detailed description of the actual sampling program is also presented, followed by a presentation of the results showing the amount of Kepone found in the environmental samples collected.

Sampling Procedures

The following procedures were used for the field sampling.

- Sediment Cores. Sediment core samples were collected using a 6-cm (2.125 in.) diameter push tube coring device with a stainless steel cutting head and 61 cm (24 in.) cellulose acetyl butyrate liner. Laboratory investigations revealed no significant uptake of Kepone on these liners. Penetration of sediments was monitored to assure at least 2.5 to 6 cm (1 to 2 in.) of water above the sediment core when retrieved. Caps were then placed on the liner and labeled. The sampling apparatus is illustrated in Figure V.2. Detailed logs were kept on each core with data on time, location, conditions, and visual observations. In Bailey Bay, sites were located using sextant readings on landmarks with specified coordinates. Completed cores were frozen and shipped for analysis.

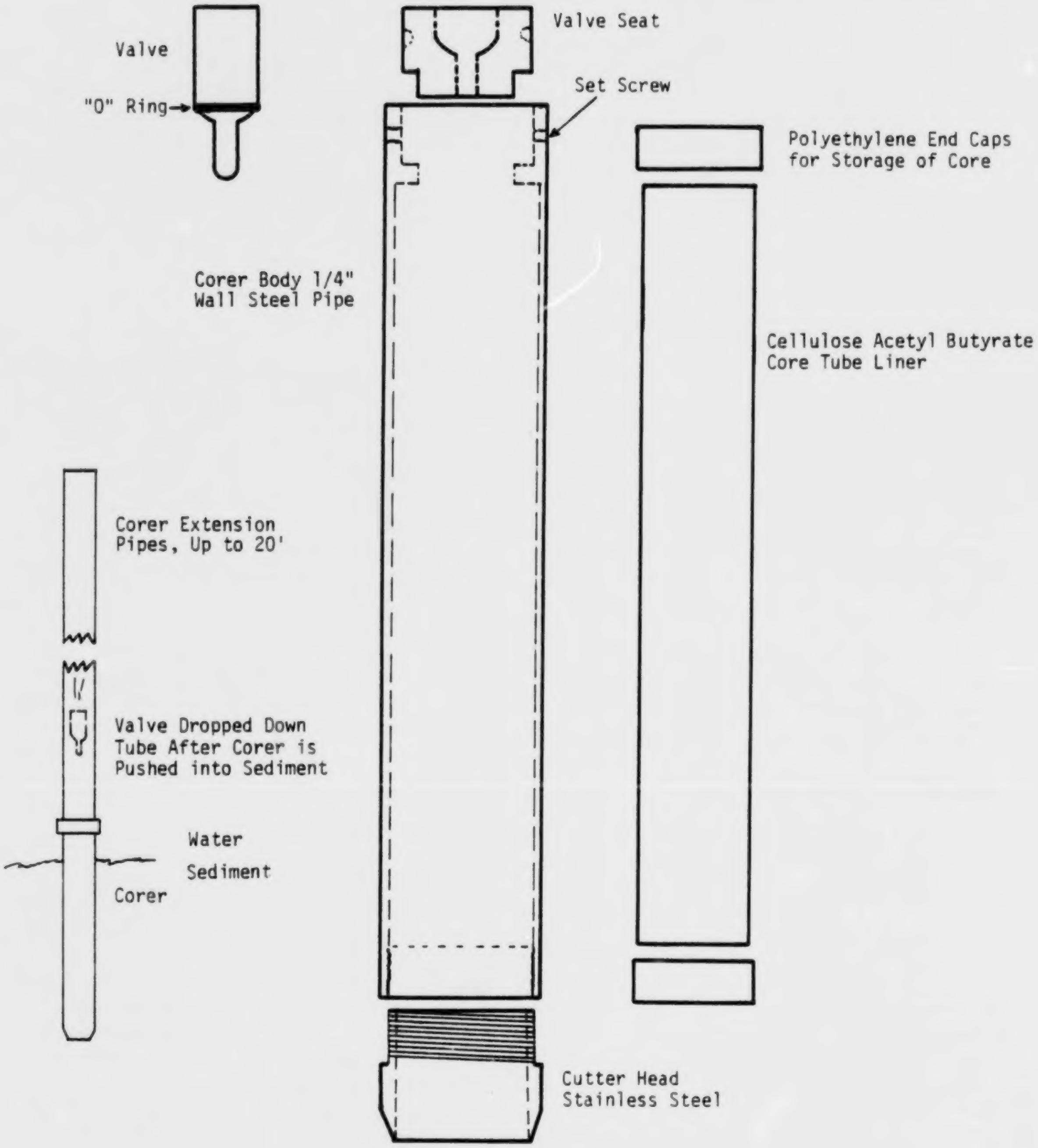
Valve
"O" Ring
Valve Seat
Set Screw
Polyethylene End Caps for Storage of Core
Corer Body 1/4" Wall Steel Pipe
Cellulose Acetyl Butyrate Core Tube Liner
Corer Extension Pipes, Up to 20'
Valve Dropped Down Tube After Corer is Pushed into Sediment
Water
Sediment
Corer
Cutter Head Stainless Steel

FIGURE V.2. Expanded View of Push Tube Coring Device Employed for Samples from Bailey Bay

- Water. Samples of water were collected in clean glass bottles and jars. Each container was first rinsed with the sample water, then filled and capped. In all cases, aluminum lined caps were used to prevent Kepone uptake by the cap.

- Soils and Sewer Slime. Samples of soils and of sewer slimes were also placed in glass jars and capped with aluminum coverings. In gathering slime samples, a metal spoon was used to scrape the slime from the inner walls of the sewer line. The spoon was thoroughly cleaned between uses.

  Standard soil samples were collected from undisturbed ground surfaces. Several subsamples of the top 2.5 cm (1 in.) from a 1 m^2 (11 ft^2) were composited to create each sample.

  To collect subsurface samples, a steep sided hole was dug to a depth of 30.5 cm (12 in.), the side was marked off into 2.5 cm (1-in.) sections, and a metal scoop used to collect soil from the desired depth. For deep core sampling at the Pebble Ammonium Nitrate site, holes were mechanically augered and split spoon samples taken using the standard penetration test method.

Analytical Methods Used for Kepone Detection

The methods and materials used in the experiments are as follows.

- Equipment. All gas chromatographic analyses of Kepone were performed on a Hewlett Packard, 5700A, gas chromatograph equipped with a ^{63}Ni electron capture detector operated in the dc pulsed mode. This gas chromatograph was also equipped with a Hewlett Packard automatic sampler, 7617A, which allowed unattended operation. Kepone retention times and peak areas were quantified with a Hewlett Packard 3370B Integrater. A borosilicate glass column 1.85 m x 2 mm ID (72.8 x 0.079 in.) was packed with 100/120 mesh Supelcoport which was coated with 1.5% SP-2250/1.95% SP-2401. The column was operated at a constant temperature of 203°C with a 45-65 ml/min flow rate of 5% methane:95% argon carrier gas. The EC detector temperature and the injection port temperature were both 300°C.

- Reagents and Materials. Florisil, PR grade, 60/100 mesh, specially processed and activated by the supplier, was re-extracted with acetone, reactivated for 2-1/2 hr at 650°C, and stored at 140°C prior to use. Na_2SO_4, reagent grade, was soxhlet extracted for 18 hr with 41:59 acetone:hexane, dried, and stored at 140°C prior to use.

Standards of Kepone were obtained from the Environmental Protection Agency Health Effects Laboratory at Research Triangle Park, North Carolina. These reference materials were 86.6% Kepone and were from Lots No. 5778 and 6104. Sets of three to six different concentrations of Kepone standards were run prior to, during, and after analysis of each batch of 25 to 30 samples.

In addition, individual Kepone standards were interspersed during the sample run after each 4 to 5 samples. The Kepone standards data were fit to a power curve to correct for the nonlinear EC detector response in the range of Kepone concentrations injected (2-1000 pg). All samples and standards contained 2% methanol to enhance a stable response of the EC detector to Kepone. All injections into the gas chromatograph were 2-µl volumes.

All solvents used during this investigation were distilled in glass, pesticide quality or equivalent. All glassware other than soxhlet extraction equipment was washed with 1 N KOH, distilled water and acetone prior to each use. The soxhlet apparatus was rinsed with either 1:3 toluene:ethyl acetate or 1:1 petroleum ether:ethyl ether and 41:59 acetone:hexane between sample extractions.

- Sample Preparation and Storage. Soil and sediment samples were dried overnight in an oven at 103°C. These dried samples were then pulverized by grinding with a mortar and pestle or with a mechanical blender. After these steps, the samples were stored in glass jars prior to their analysis. Water samples were collected and stored in glass bottles with Teflon or aluminum-lined caps.

- Preparation of Standard Reference Sediment. Approximately 4 kg (9 lb) dry weight of a Bailey Bay sediment was prepared as a standard reference material to be used throughout this investigation. This sample was pulverized by mechanical blending and was tumbled continuously for 7 days in a glass bottle to ensure exhaustive homogenization. All samples of the "standard Bailey Bay sediment" were subsamples of this reference sediment.

- Sediment Extraction. All sediments and soil samples were extracted with approximately 200 to 225 ml of solvent in a soxhlet extraction tube fitted with an Allihn type condenser.

Two different solvent systems were used for extracting the solid samples depending upon the anticipated levels of Kepone and Kepone interferences. A discussion of the sample types extracted by each solvent system is presented later. Each of the solvent extraction methods and cleanup techniques, where applicable, is presented below.

Method A. A 10.00 g (0.022 lb) aliquot of dried, pulverized sample of soil sediment was mixed with 3.33 g (0.00734 lb) of anhydrous Na_2SO_4, placed into a Whatman cellulose extraction thimble, and soxhlet extracted for 18 to 20 hr with 200 ml of 1:3 toluene:ethyl acetate. This extract was concentrated in a rotary evaporator (water bath temperature: ∿38°C) and diluted to a final volume of 25 ml.

Method B. A 10.00 g (0.022 lb) aliquot of dried, pulverized sample of soil or sediment was mixed with 3.33 g (0.00734 lb) of anhydrous Na_2SO_4, placed into a Whatman cellulose extraction thimble, and soxhlet extracted for 18 to 20 hr with 225 ml of 1:1 petroleum ether:ethyl ether.

The sample was concentrated by rotary evaporation (water bath temperature: 38°C) to near dryness and was diluted to a 10-ml final volume with petroleum ether.

- Water Extraction. A 10-ml aliquot of water sample and 1 ml of organic solvent were placed into a 15-ml, graduated, conical, centrifuge tube with a Teflon-lined screwcap. Kepone was extracted from the water into the organic solvent layer by vigorous shaking on a wrist action shaker for 20 to 30 min. Samples were centrifuged at 3000 rpm for 1 to 2 min to separate the phases. The organic solvent layer was drawn off and the centrifuge-tube washed with two 100 to 200-μl aliquots of solvent. These washings were combined with the original solvent layer and diluted to a 1-ml volume. Unless otherwise specified, this analysis was performed on a total water sample which included both soluble and particulate-attached Kepone.

  Two different organic solvents were used for this water extraction, a 1:3 toluene:ethyl acetate mixture and a 1:1 petroleum ether:ethyl ether mixture. The petroleum ether:ethyl ether extracts were evaporated to near dryness and diluted to a 1-ml volume with petroleum ether prior to further processing.

- Extract Cleanup. Sediments, soils, and waters extracted with the petroleum ether:ethyl ether solvent mixture were subjected to an extract cleanup on a Florisil column to separate the Kepone fraction from potential PCB interferences. This cleanup was performed on microcolumns 4 mm ID x 180 mm (0.16 x 7.1 in.). The column was plugged with a small amount of glass wool and 0.8 g (0.002 lb) of Florisil was added while tapping; 0.8 g (0.002 lb) of anhydrous Na_2SO_4 was added on top of the Florisil. This column was then washed with 10 ml of petroleum ether. Immediately after this washing 2-ml of soil or sediment extract or 1-ml of water extract was placed on top of the column. The PCB containing fraction was eluted with 9 ml of 2% methanol:4% benzene:94% hexane. The Kepone was then eluted with 10 ml of 2% methanol:24.5% toluene:73.5% ethyl acetate and adjusted to a 10-ml final volume.

Analytical Method Used for Hexachlorocyclopentadiene Detection

- Sample Preparation and Storage. Soil samples from the Pebbled Ammonium Nitrate site were stored in sealed containers. Subsamples of the moist soil samples were taken for analysis.

- Soil Extraction. A 1.00-g (0.0022-lb) aliquot of moist soil was placed into a 15-ml, graduated, conical centrifuge tube with a Teflon-lined screw cap. An 8-ml portion of 2% methanol:24.5% toluene:73.5% ethyl acetate was added to the centrifuge tube; the tube was capped, and the sample was shaken for 18 hr on a wrist-action shaker. Samples were centrifuged at 3000 rpm for 1 to 2 min to separate the phases. The organic solvent layer was drawn off and the centrifuge tube was rinsed with two 1-ml aliquots of solvent. These washings were combined with the original solvent and diluted to a 10-ml volume.

- Gas Chromatographic Analysis. All equipment was as described above for Kepone analysis; however, operating conditions were as follows: injection port temperature, 250°C; EC detector temperature, 300°C; column temperature, 105°C.

- Reagents and Materials. Sample of reagent grade hexachlorocyclopentadiene for standardization was obtained from ICN-K&K Labs Division, Cat. No. 14522.

Results and Discussion

The solvent extraction techniques were evaluated for the recovery of Kepone from soils, sediments and water.

- Solvent Extraction of Soils and Sediments. An evaluation was made of the recovery of both native Kepone and Kepone added in the laboratory from the standard Bailey Bay sediment by both the toluene:ethyl acetate and the petroleum ether:ethyl ether solvent mixtures. The data presented in Table V.1, Part A, show the mean value for 19 replicates of the standard sediment and the recovery of added Kepone from seven additional replicate analyses by the toluene:ethyl acetate solvent system. These data verify that this mixed solvent system recovers essentially 100% of the Kepone added to the sediment samples with a small standard deviation of approximately 7%. The standard deviation from the mean of 19 replicates was approximately 11%. Based upon the excellent recovery of the added Kepone from these sediment samples and the good precision of replicate analyses, the toluene:ethyl acetate solvent mixture was the solvent system of choice for most of the solid samples analyzed during this investigation.

The recovery of Kepone by soxhlet extraction with toluene:ethyl acetate can be compared to the recovery by soxhlet extraction with a petroleum ether:ethyl ether solvent mixture as is shown in Table V.1, Part B. These data, for the recoveries of native Kepone and laboratory added Kepone, indicate that the petroleum ether:ethyl ether solvent mixture followed by a micro-Florisil column cleanup of the extract recovers a smaller proportion of the Kepone than does the toluene:ethyl acetate solvent system. The Kepone concentration for 10 replicates of spiked Bailey Bay sediment samples was approximately 68% of that found for replicates of the same sediment by the toluene:ethyl acetate extraction. The recovery of added Kepone was approximately 77% as compared to essentially 100% for the toluene:ethyl acetate solvent. Based upon the behavior of standards (unpublished data), it is felt that the loss of the Kepone during the petroleum ether:ethyl ether extraction and cleanup occurs during the cleanup step on the micro-Florisil column. Because of the lower Kepone recoveries resulting from the irreversible retention of Kepone by the micro-Florisil columns, this solvent system was used for only those samples which contained lower Kepone concentrations or concentrations similar to the level of the PCB interferent compounds. Its use was necessary on these samples since toluene:ethyl acetate solutions cannot be put through micro-Florisil cleanup.

TABLE V.1. RECOVERY OF KEPONE FROM BAILEY BAY SEDIMENT SAMPLES

Part A

Sample No.	Kepone Concentration µg/g	Percent Recovery of Added Kepone
19 Replicates	Range: 0.98 - 1.38	---
	$\bar{x} = 1.17 \pm 0.13$	---
BB-TEA-S-1	3.05	94.0
BB-TEA-S-2	3.15	99.0
BB-TEA-S-3	3.01	92.0
BB-TEA-S-4	2.19	102.0
BB-TEA-S-5	2.17	100.0
BB-TEA-S-6	2.31	114.0
BB-TEA-S-7	2.12	95.0
		$\bar{y} = 99.4 \pm 7.3$

Extracting Solvent: 1:3/Toluene:Ethyl Acetate

Sample Size: 10.0 g

Kepone Added: 1.00 µg/g or 2.00 µg/g

Part B

10 Replicates	Range: 0.68 - 0.88	---
	$\bar{x} = 0.79 \pm 0.05$	---
BB-PE-S-1	1.62	83
BB-PE-S-2	1.57	78
BB-PE-S-3	1.78	99
BB-PE-S-4	1.61	82
BB-PE-S-5	1.24	45
		$\bar{y} = 77.4 \pm 19.8$

Extracting Solvent: 1:1/Petroleum Ether:Ethyl Ether

Extract Cleanup: Microflorisil Column

Sample Size: 10.0 g

Kepone Added: 1.00 µg/g

To evaluate the effect of soxhlet extraction time on the recovery of Kepone from sediment samples, replicates of the contaminated Bailey Bay standard sediment were extracted for four different time intervals. The data from this study are shown in Table V.2. The mean values of the Kepone concentrations in replicate samples are indistinguishable for each of these time periods, suggesting that the toluene:ethyl acetate extracting solvent employed is capable of removing essentially all of the Kepone from the sediments in less than a 12-hr period. During this investigation, all of the soxhlet extractions were run for 18 to 20 hr.

TABLE V.2. KEPONE EXTRACTION FROM BAILEY BAY SEDIMENT SAMPLES

Extracting Time-hr	Kepone Concentration-μg/g
12	1.26 ± 0.08
18	1.15 ± 0.16
24	1.09 ± 0.04
36	1.19 ± 0.35
All samples	1.17 ± 0.07

Extracting Solvent: 1:3/Toluene:Ethyl Acetate
Sample size: 10.00 g

The majority of soil and sediment samples examined for Kepone content were extracted using the toluene:ethyl acetate organic solvent extraction system. These samples included those sediments which were obtained from Bailey Creek and Bailey Bay areas, other sediments known to contain elevated Kepone concentrations, soil samples from the areas adjacent to the Life Sciences plant and Allied Semi-Works plant, sewer pipe scrapings, and all sediments and soils which were obtained from laboratory investigations. Those soil and sediment samples which were extracted using the petroleum ether:ethyl ether solvent extraction system include all sediment samples from the main channel of the James River and all the terrestrial soil samples obtained from any location other than that known to be within the immediate sphere of influence of the Life Science plant or the Allied Chemical Semi-Works plant.

The limit of detection for Kepone analysis in soils and sediments when using the toluene:ethyl acetate solvent system depends to an extent upon the levels of other contaminants (especially PCBs and pesticides) in the samples since this procedure does not include a step for removal of potential interferences. For soil and sediment samples with only small quantities of

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interfering compounds, the limit of detection is approximately 0.0005 µg/g-dry weight. This concentration corresponds to an integrated Kepone peak area of 100 micro-volt-seconds. Samples having particularly low levels of interference include most of the subsurface samples from soil cores collected from Nitrogen Park, the Pebbled Ammonium Nitrate site, the sanitary landfill, Moody Creek cores, and a few cores from Bailey Creek. Kepone concentrations which are reported as "less than" numbers but are greater than the stated detection limit are due to the presence of interfering materials in the sample extracts. The approximate limit of detection for Kepone in soil and sediments analyzed by the petroleum ether:ethyl ether extraction-Florisil cleanup technique is 0.001 µg/g. This concentration corresponds to an integrated peak area of 100 micro-volt-seconds. For some of the samples of James River solids, the use of peak height rather than peak area was necessary. The limit of detection for these samples was approximately 0.003 µg/g. A complete listing of the individual soil and sediment samples extracted by the toluene:ethyl acetate and the petroleum ether:ethyl ether systems is given in Appendix C.

Battelle, together with six other laboratories, participated in a round-robin analysis of Kepone-contaminated sediments. The analysis was organized by the Health Effects Research Laboratory of EPA-Research Triangle Park as a part of the overall EPA Mitigation Feasibility Project to ensure comparability of analytical data. The results of the Battelle analyses of the samples spiked with Kepone indicated an average recovery of 93.3%. This recovery compares extremely well with the 81.5% average recovery for all laboratories participating. These data demonstrate that the toluene:ethyl acetate extraction technique developed for this research is a valid technique which provides recovery of Kepone from sediments that is equal to or greater than the recovery achieved by any other analytical method normally employed for Kepone analyses.

- Solvent Extraction of Natural Waters. An initial evaluation of several solvents including 1:1 petroleum ether:ethyl ether, 1:3 toluene:ethyl acetate, 41:59 acetone:hexane, and iso-octane revealed that the toluene:ethyl acetate solvent mixture was a superior solvent system for recovering Kepone spikes from artifical water samples. Therefore, this solvent system was used nearly exclusively for analyses of all natural waters and for water samples from laboratory investigations.

  Three different contact times of water-solvent agitation during Kepone extraction were examined to determine if a long contact time was required. Twenty-, forty-, and sixty-mil extractions were performed on replicates of one environmental sample. The data indicated that a constant concentration of Kepone was found in the samples regardless of the contact time. Therefore, all subsequent solvent extractions of natural water samples were agitated for 20 to 25 min.

  Many of the natural water samples were stored for a period up to 4 weeks prior to their analysis. To determine if this storage had any adverse effects on the quantification of the total Kepone content of the samples, several of the bottles which had contained the stored samples were rinsed with a quantity of the toluene:ethyl acetate solvent. Aliquots of these rinsings were then examined for their Kepone concentrations. In all cases, less than 0.01% of the Kepone in the total water sample was found associated with the glass walls of the storage container. These results confirmed that, even at very low concentrations of Kepone, the storage of samples for long periods of time did not adversely affect measurement of the total Kepone concentrations in these natural water samples.

The efficiency of the toluene:ethyl acetate solvent in removing Kepone from natural water samples is demonstrated by the data in Table V.3. The overall recovery of 200 ppt (parts per trillion) of Kepone added to replicates of a water sample from the James River was approximately 97.5% for six replicates. The recovery of a 50 ppt Kepone spike added to replicates of a Columbia River water sample was approximately 87.8% for five replicates. In addition to this overall high efficiency of extraction that the toluene:ethyl acetate solvent provides, this solvent system also yields good precision on replicate analyses of individual samples. The data in Table V.4 show the Kepone concentrations in nine replicates of an environmental water sample containing approximately 2.5 ppb of Kepone. The standard deviation from the mean concentration for these analyses was approximately 5%.

The recovery of Kepone from environmental water samples using the toluene: ethyl acetate solvent can be compared to the recovery obtained when the 1:1 petroleum ether:ethyl ether solvent is used. The data in Table V.5 show the recovery of 100 ppt of Kepone added to a James River sample when the petroleum ether:ethyl ether system followed by a micro-Florisil extract cleanup is used. In this case, the recovery of the added Kepone averaged approximately 70% for four replicate samples. This recovery compares favorably with the average recovery of Kepone from sediments when petroleum ether:ethyl ether is used as the extracting solvent; this solvent system averages approximately a 77% recovery of the added Kepone from sediments. The comparison of the toluene: ethyl acetate solvent with the petroleum ether:ethyl ether solvent was necessary since a few water samples were extracted with petroleum ether:ethyl ether and subjected to the micro-Florisil cleanup prior to GC analysis. These samples included approximately 25 filtered James River water samples from which the particulate materials were analyzed separately, and samples obtained from the Virginia American Water Company.

The data presented in Table V.6 compare two analysis techniques, toulene: ethyl acetate extraction and petroleum ether:ethyl ether extraction followed by Florisil cleanup, for recovery of ppt levels of Kepone from water samples from the Hopewell area. On the basis of the data previously shown in Table V.3, it is clear that the toluene:ethyl acetate solvent system recovers 85 to 100% of the Kepone spiked at the 50 to 200 ppt levels in natural water samples.

TABLE V.3. RECOVERY OF KEPONE FROM JAMES RIVER WATER SAMPLES

Sample No.	Kepone Concentration μg/ℓ	Percent Recovery of Added Kepone
	James River Water Samples	
224-a	0.025	---
224-b	0.038	---
224-c	0.056	---
	$x = 0.040 \pm 0.016$	
224-d	0.217	88.5
224-e	0.229	94.5
224-f	0.245	102.5
224-g	0.243	101.5
224-h	0.243	101.5
224-i	0.235	97.5
	$\bar{x} = 0.235 \pm 0.011$	$\bar{y} = 97.7 \pm 4.7$
	Columbia River Water Samples	
2958-75-5	0.0333	66.6
2958-75-6	0.0492	98.4
2958-75-7	0.0435	87.0
2958-75-8	0.0490	98.0
2958-75-9	0.0446	89.2
	$\bar{x}$ 0.0439 ± 0.0065	$\bar{x} = 87.8 \pm 12.9$

Extracting Solvent:	1:3/Toluene:Ethyl Acetate
Sample Volume:	10 ml
Kepone Added:	0.200 μg/ℓ or 0.050 μg/ℓ

TABLE V.4. PRECISION OF KEPONE ANALYSES FOR ENVIRONMENTAL WATER SAMPLES

Samples No.	Kepone Concentration µg/ℓ
Seep No. 1-a	2.47
1-b	2.49
1-c	2.43
1-d	2.77
1-e	2.57
1-f	2.50
1-g	2.70
1-h	2.66
1-i	2.75
	$\bar{x}$ = 2.59 ± 0.13

Extracting Solvent: 1:3/Toluene:Ethyl Acetate

Sample Volume: 10 ml

The data in Tables V.5 and V.6 indicate that the water analysis method employing a petroleum ether:ethyl ether extraction followed by a Florisil cleanup step for removal of interferences recovers 60 to 70% of Kepone in the water at the low ppt levels. This comparison of recoveries is consistent with the recoveries of Kepone from sediments by these two technqiues. Kepone recoveries by the toluene:ethyl acetate extraction technique are quite good at all levels of contamination and the proportion of Kepone recovered by the petroleum ether:ethyl ether extraction-Florisil cleanup technique appears to be relatively constant at widely differing Kepone contamination levels. Consequently, it is suggested that the recovery of natural levels of Kepone contamination from James River water samples by the petroleum ether:ethyl ether extraction-Florisil cleanup method yields recoveries of approximately 60%.

TABLE V.5. RECOVERY OF KEPONE FROM JAMES RIVER WATER SAMPLES

Sample No.	Kepone Concentration μg/ℓ	Percent Recovery of Added Kepone
213-a	0.017	---
213-b	0.007	---
	$x = 0.012 \pm 0.007$	
213-c	0.062	50.0
213-d	0.085	73.0
213-e	0.084	72.0
213-f	0.098	86.0
	$\bar{x} = 0.082 \pm 0.015$	$\bar{y} = 70.3 \pm 14.9$

Extracting Solvent: 1:1/Petroleum Ether:Ethyl Ether

Extract Cleanup: Micro-Florisil column

Sample Volume: 10 ml

Kepone Added: 0.100 μg/ℓ

TABLE V.6. EXTRACTION OF TRACE CONCENTRATIONS OF KEPONE FROM VIRGINIA AMERICAN WATER COMPANY SAMPLES BY TWO SOLVENT SYSTEMS

Sample	Measured Kepone Concentration - μg/ℓ Toluene:Ethyl Acetate Extraction	Measured Kepone Concentration - μg/ℓ Petroleum Ether:Ethyl Ether Extraction Plus Florisil Cleanup	Petroleum Ether:Ethyl Ether Conc. as % of Toluene:Ethyl Acetate Concentration
Hopewell Domestic Water 9/27/78 0900	0.011, 0.0081	0.0037	38.5
Hopewell Domestic Water 9/27/78 1205	0.0026, 0.0022	0.0018	75.0
Hopewell Domestic Water 9/27/78 1515	0.0070	0.0044	62.9
Hopewell Industrial Water 9/27/78 0900	0.015	0.012	80.0
Hopewell Raw Water 9/27/78 0900	0.025, 0.025	0.014	56.0
			$\bar{x} = 62.4 \pm 16.4$

In order to assess the efficiency of Kepone extraction by toluene:ethyl acetate at higher Kepone concentrations, several samples containing elevated Kepone concentrations were extracted sequentially with two separate aliquots of toluene:ethyl acetate. The data for recovery of Kepone from these water samples, which contained from 19 to 394 μg/ℓ (ppb) of Kepone, are presented in Table V.7. It is apparent from these data that a single extraction with toluene:ethyl acetate removes greater than 90% of the Kepone in the samples. On the basis of these data, even at these high levels of Kepone contamination, only a single extraction of all natural water samples was required.

TABLE V.7. SEQUENTIAL EXTRACTION OF KEPONE FROM NATURAL WATERS

Sample Number	Kepone Concentration in First Extraction-μg/ℓ	Kepone Concentration in Second Extraction-μg/ℓ	Percent of Total Recovered by Single Extraction
Seep #5	18.6	0.71	96.3
0-19 RO-2	48.7	1.5	97.0
0-19 RO-3	358.0	35.8	90.9
0-19 RO-1	370.0	17.4	95.5

The results of these procedural evaluations and determinations for the toluene:ethyl acetate solvent system as an extracting medium for Kepone from natural waters has shown it to be excellently suited for this purpose. Precision of replicate analyses is very good, recovery of sub-ppb Kepone spikes is essentially quantitative, and the extraction is neither time-consuming nor difficult. This method is, of course, subject to PCB interferences; however, these interferences do not seem to be a major difficulty at Kepone concentrations of 100 ppt or higher. In most cases, PCB concentrations in the water samples examined were so low that insignificant interferences occurred even at Kepone concentrations of less than 50 ppt.

The limit of detection for Kepone analysis of water samples when using the toluene:ethyl acetate solvent extraction technique is partially dependent upon the levels of some other contaminants in the samples (especially PCBs and pesticides) since there is no removal of potential interferences in this procedure. The limit of detection for Kepone in natural water samples with low concentrations of interfering compounds is approximately 0.025 μg/ℓ. This concentration corresponds to an integrated peak area of 100 micro-volt-seconds. The majority of petroleum ether:ethyl ether extractions of natural water samples was performed prior to obtaining the electronic peak integrator. Therefore, the limit of detection for these samples is based upon a peak of two times the baseline noise of the strip chart recorder at its most sensitive setting

(0.1 millivolt full scale). This peak height corresponds to a Kepone concentration of approximately 0.006 μg/ℓ but is sample dependent. The water samples obtained from the Virginia American Water Company were large volume samples which were concentrated by evaporation. The limit of detection for Kepone in these samples (based on an integrated peak area of 100 microvolt-seconds) is 0.0004 μg/ℓ .

Solvent Extraction of Soils for Hexachlorocyclopentadiene

The recovery of hexachlorocyclopentadiene (HCP) from two soil types by the toluene:ethyl acetate extraction procedure developed was evaluated. The data for the recovery of HCP from a sand sample and from a sample of Bailey Creek sediment (demonstrated to contain no HCP) are given in Table V.8. The recoveries were generally good and were consistent for each sample type. The recovery of less than 100% of the added hexachlorocyclopentadiene is thought to be due to the fact that the extractions are performed at room temperature due to HCP volatility and potential for loss at elevated temperatures. HCP analyses were performed only on soil samples from the Pebbled Ammonium Nitrate site. Nearly all of these samples were very sandy and similar to the sand used in this HCP recovery investigation. Therefore, the recovery that was achieved for the HCP spiked into the sand samples quite likely approximates the recovery of HCP from the PAN samples.

Related Analyses

The following heavy metals were run by atomic absorption using a graphite furnace and hollow cathode lamps: arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), and antimony (Sb). Analyses were performed by the method of known additions. A deuterium background corrector was used in the analysis of As, Cd, Pb, and Sb.

Total Mercury Concentration in Sediment--

The determination of total mercury was accomplished by flameless atomic absorption (Windom, 1973; Kalb, 1970). Wet sediment was digested in nitric acid, permanganate, and persulfate on a water bath at 60°C overnight. The resultant solution was then treated with hydroxylamine hydrochloride to reduce excess oxidizing reagents. Stannous chloride was added to reduce the mercury to its elemental form. The mercury was next purged with nitrogen gas which carried the volatile mercury through a silver foil trap. Mercury was captured as an amalgam on the foil while organic and moisture vapors were vented. The silver foil was then rapidly heated and mercury driven through a quartz absorption cell. The mercury absorption peak was measured with a strip chart recorder receiving the spectrophotometer signal. Standard mercury solutions were used to calibrate the instrumentation.

Sediment Size Fractionation--

Size fractionation was performed using the method of Jackson (1956). Samples were dispersed in distilled water overnight and sieved through a 200 mesh sieve. The material retained on the sieve, >74 μ, was dried and weighed as the sand fraction. The material which passed through the sieve was centrifuged at 750 rpm for 3.3 min and decanted. The settled material, 74 μ to 2 μ, was dried and weighed as the silt fraction. The decant was centrifuged at 2400 rpm for 35 min, decanted, dried and weighed as the clay fraction, <2 μ.

TABLE V.8. RECOVERY OF HEXACHLOROCYCLOPENTADIENE FROM SOIL AND SEDIMENT SAMPLES

Sample Description and No.	Hexachlorocyclopentadiene Concentration μg/g	% Recovery of Added Hexachlorocyclopentadiene
Sand - 54-1	0.136	81.6
54-2	0.143	85.8
54-3	0.150	89.9
54-4	0.132	78.7
		$\bar{x}$ + 84.0 ± 4.9
Bailey Creek Sediment - 54-7	0.123	73.8
54-8	0.110	65.5
54-9	0.114	68.4
54-10	0.116	69.4
		$\bar{x}$ = 69.3 ± 3.4

Extracting Solvent: 1:3/Toluene:Ethyl Acetate

Sample Size: 1.00 g

Hexachlorocyclopentadiene Added: 0.167 μg/g

GC/MS Identification of Organic Contaminants--

Approximately 20 g (0.044 lb) of wet sediment, (equivalent to approximately 8.5 g (0.019 lb) dry weight, were mixed with 20 g (0.044 lb) of dry Na_2SO_4 and extracted with 200 ml of acetone:hexane (41:59) for 18 hr in a soxhlet extraction apparatus. The acetone:hexane extract was dried through 15 g (0.033 lb) Na_2SO_4, concentrated by rotoevaporation at 37°C, and diluted to a final 50 ml volume with hexane. In addition, 10.0 g (0.022 lb) aliquots of dried and ground sediments were extracted with approximately 200 ml of petroleum ether:ethyl ether (1:1), toluene:ethyl acetate (1:3), or acetone: hexane (41:59). Each of these sediment extracts was reduced to a final volume of 25 ml.

The organic compounds present in the concentrated extracts were identified by gas chromatography-mass spectrometry using a Hewlett Packard 5980A gas chromatograph/mass spectrometer equipped with a 5934A data system. The instrument was operated in the electron impact mode.

The separations were achieved on a 1.85 m x 2 mm ID (72.8 x 0.079 in.) 1.5% SP2250-1.95% SP2401 column on 100/120 Supelcoport. The temperature program used was an initial temperature of 70°C held for 5 min followed by an 8°C/min program to 240°C. This final temperature held for the remainder of the 40 min run. The GC injection port temperature was either 300°C or 350°C and the temperature of the transfer line between the GC and the mass spectrometer was 250°C. A glass jet separator was used to prevent the helium carrier gas from entering the mass spectrometer. Since the concentrations of the compounds in the samples were low, a large volume (50 μl) of sample was injected on column and a high mass spectrometer gain (G = 7L) was used.

Details of The Field Sampling Program

Bailey Bay--

The main thrust of the initial field sampling program was directed at Bailey Bay. Various samples were taken from the Bay in order to provide a better understanding of the transport of Kepone through the Bay. Samples were taken at the mouth of Bailey Creek, mid-Bay, and the northeast corner of the Bay near Jordan Point for determination of the particle size distribution of the bottom sediments.

To establish sampling sites in the Bay, a grid network was overlayed with the vertical axis on magnetic north and spacings to yield squares of 305 m (1000 ft) on a side. Every other square (in a checkerboard fashion) was then designated for core sampling as illustrated in Figure V.3. Thus, 31 sites were identified for sampling. This is 37.5% greater than the minimum number that would be necessary to evaluate contaminated sediments with the EPA Region IX formula for aquatic sediments (EPA, 1974). Seven of these cores were divided into 2.5 cm (1 in.) thick slices to yield a picture of how Kepone content varies with depth.

Also in Figure V.3, four sampling locations are shown that were designated for heavy-metal and broad-spectrum GC/MS organic analysis. These samples serve to determine the presence of other contaminants that could potentially affect alternative Kepone cleanup actions.

The Hopewell Area--

A comprehensive sampling plan for Bailey Creek, Gravelly Run, the terrestrial areas of the town of Hopewell, the municipal sewage treatment plant area, and the municipal landfill area was established to quantify inflows of Kepone to Bailey Bay and the James River system.

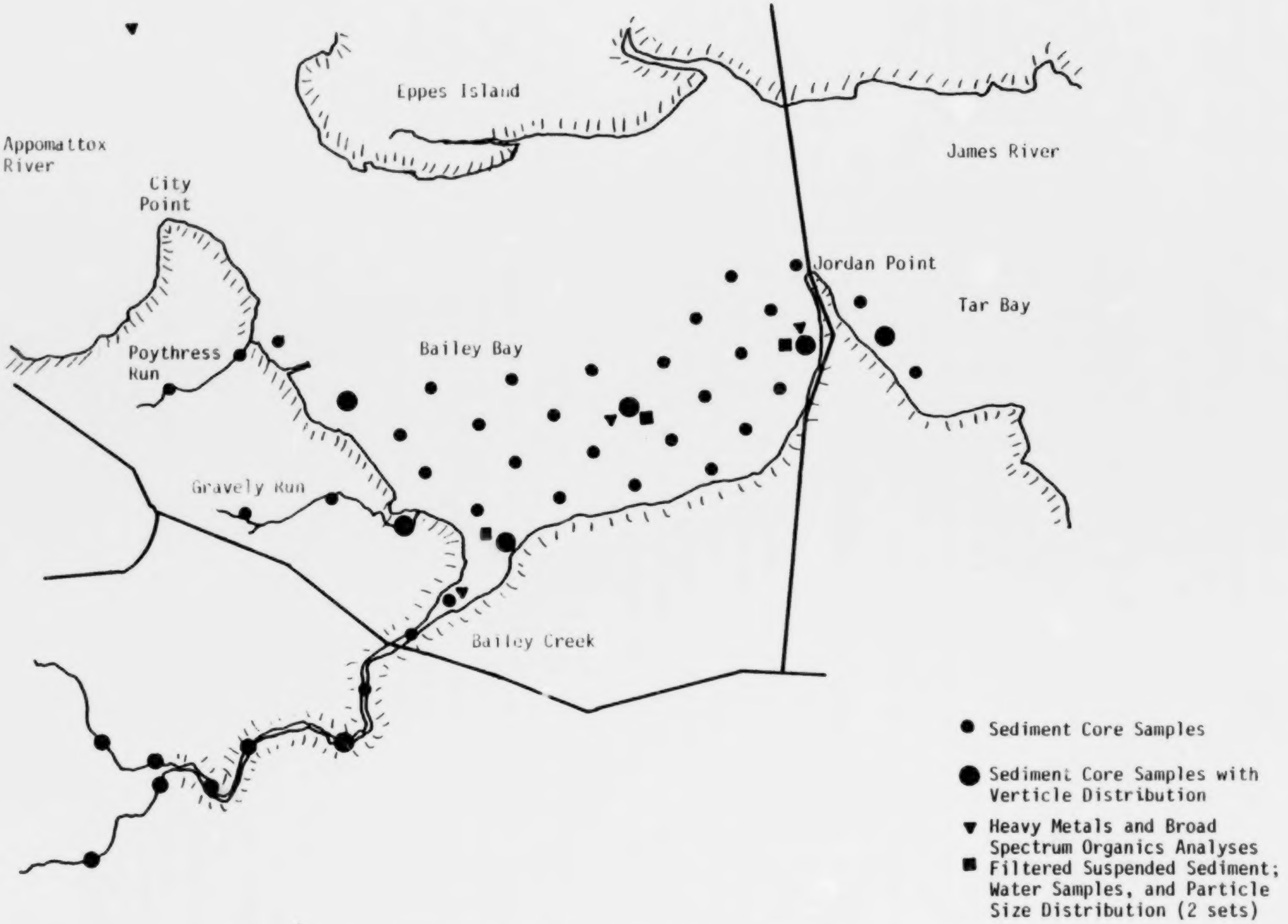

Appomattox River
City Point
Eppes Island
James River
Jordan Point
Tar Bay
Poythress Run
Bailey Bay
Gravely Run
Bailey Creek
● Sediment Core Samples
● Sediment Core Samples with Verticle Distribution
▼ Heavy Metals and Broad Spectrum Organics Analyses
■ Filtered Suspended Sediment; Water Samples, and Particle Size Distribution (2 sets)

FIGURE V.3. Sampling Pattern for Bailey Bay and Tributaries

Sample Locations--

Sediment, soil and water samples were obtained from several different locations.

- Sediment. Because it was hypothesized that significant amounts of Kepone are associated with the sediments of creeks flowing into Bailey Bay, sediment cores at 610-m (2000-ft) intervals beginning at the creek mouth were taken in Bailey Creek, Cattail Creek, Gravelly Run, and Poythress Run. The upstream limit of sampling was State Highway 156 for Bailey Creek, a point 305 m (1000 ft) above any possible influence of the landfill for Cattail Creek, the State Highway 10 bridge for Gravelly Run, and Station Street for Poythress Run. For these locations, sediment samples were a composite of three stations on a bank-to-bank cross section. The map in Figure V.3 plots the location of sediment samples taken from Hopewell area creeks.

- Soil. Soil samples were taken at several locations in the Hopewell area to determine the extent of Kepone contamination in the soils of the area's watersheds. The sampling points were located so as to get a approximate mapping of the distribution and magnitude of soil Kepone levels, thereby giving insight into the possible significance of contamination of the James River from terrestrial sources. Particular attention was paid to the area around the former Life Science Products plant. Other points were dispersed throughout the city of Hopewell and the area immediately surrounding the city as illustrated in Figure V.4. Site descriptions are given in Table V.9.

- Water. Water samples were taken to measure inputs of Kepone from streamflow, runoff, ground water, and seeps. Streamflow samples were collected from several locations on Bailey Creek, Cattail Creek, Gravelly Run, Moody's Creek, Poythress Run, and Cabin Creek. When possible, each station was sampled on two days: one during low flow; one during a period of high runoff.

  Samples of storm runoff were also taken from areas suspected to contain high Kepone concentrations (Life Science Plant area, landfill area), as well as from representative points throughout the city. Sample sites are displayed in Figure V.5 and described in Table V.10. Ground-water samples for Kepone analysis were taken from seven test wells bored by the State Water Control Board and two private wells in the area. Water was also sampled in the vicinity of the Kepone lagoon. Samples were collected from within the lagoon, in a puddle outside the dike, and from ground-water seeps flowing into Bailey Creek immediately below the lagoon.

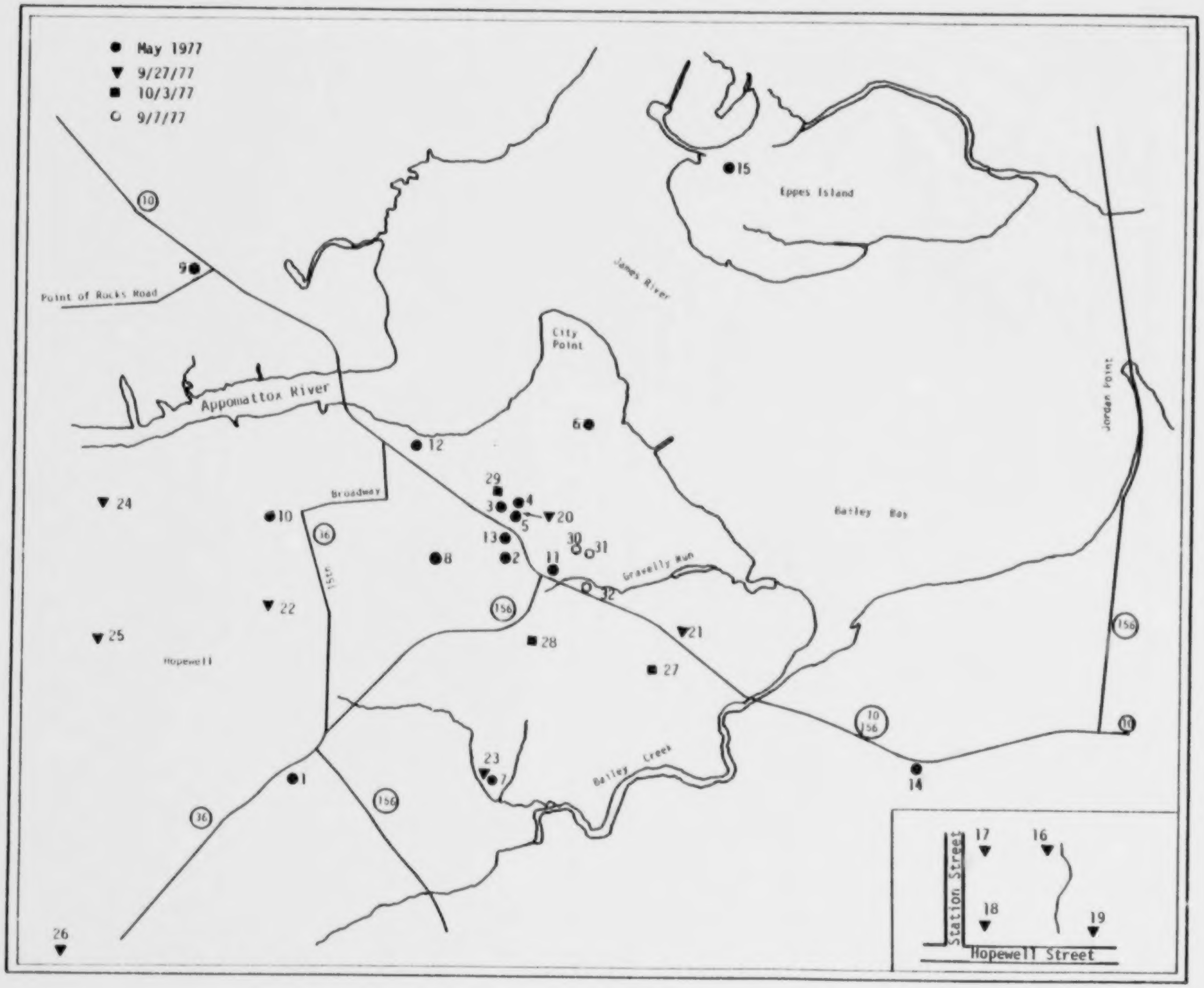
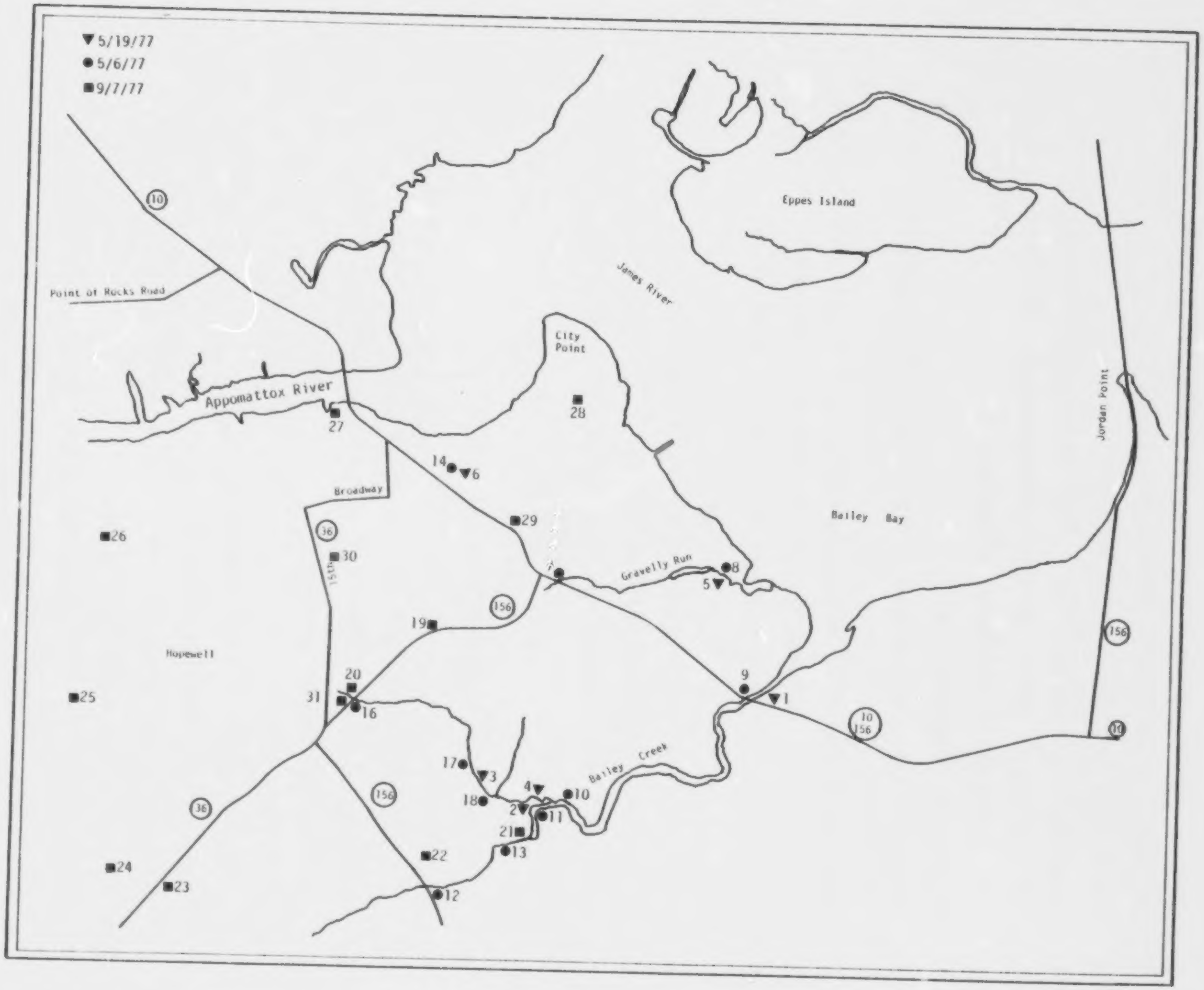

● May 1977
▼ 9/27/77
■ 10/3/77
○ 9/7/77
10
9
Point of Rocks Road
Appomattox River
James River
Eppes Island
15
City Point
6
12
29
3
4
5
20
13
30
31
8
2
11
32
Gravelly Run
Bailey Bay
Jordan Point
Broadway
10
16
15th
24
22
25
Hopewell
156
28
21
27
156
10 156
10
23
7
Bailey Creek
1
156
36
14
26
Station Street
17
16
18
19
Hopewell Street

FIGURE V.4. Sites for Soil Samples in Hopewell

TABLE V.9. SITE DESCRIPTIONS FOR SOILS SAMPLES

1. Church, north corner of Boston and Sunnyside Streets.
2. Baseball field behind James School.
3. North side Cavalier Ice Plant.
4. Nitrogen Park between State Well and Hopewell Streets.
5. Off northeast corner of Life Sciences Plant Building.
6. Park, corner of Burnside and Allen.
7. Near main Pump Station.
8. Grove of trees on LaPrade Street across from Industrial Piping and Supply.
9. Southwest corner of State Highway 10 and Point of Rocks Road.
10. Apartments, southwest corner of 20th and Broadway.
11. North side of State Highway 10 at Civic Clubs sign.
12. Apartment, Corner of 2nd and Eppes.
13. Park, 100' east of the Hopewell News Building.
14. South side of State Highway 10 at FOP Lodge Road.
15. Just off road between Shirley Plantation and Eppes Island.
16. Nitrogen Park.
17. Nitrogen Park.
18. Nitrogen Park.
19. Nitrogen Park.
20. Life Science site next to the railroad track.
21. 20 feet north of Highway 10 across from the PAN site.
22. DuPont School playground.
23. Main Pump Station.
24. Appomattox No. 2 Pump Station
25. Sussex Drive Pump Station.
26. Western Street Pump Station.
27. Pebble Ammonium Nitrate site.
28. Black field where liquid waste from tankers was disposed of.
29. Northwest corner of the Life Sciences site.
30. North side of Semi-Works.
31. West side of Semi-Works.
32. Between Gravelly Run and State Highway 10 across from the first Allied effluent.



▼ 5/19/77
● 5/6/77
■ 9/7/77
Point of Rocks Road
10
Appomattox River
27
James River
Eppes Island
City Point
28
Jordan Point
14
6
Broadway
29
Bailey Bay
26
36
30
15th
7
Gravelly Run
8
5
156
19
Hopewell
9
1
156
20
31
16
25
10
156
10
17
3
4
10
Bailey Creek
18
2
11
156
36
21
13
22
24
23
12

FIGURE V.5. Surface Water and Runoff Sample Locations

TABLE V.10. SITE DESCRIPTION FOR RUNOFF AND CREEK WATER SAMPLES

1. Bailey Creek at State Highway 156.
2. Bailey Creek just above Cattail Creek.
3. Cattail Creek at power line above Landfill.
4. Cattail Creek just above Bailey Creek.
5. Gravelly Run at Continental Can Road.
6. Drainage ditch at Station Street east of crossing.
7. Gravelly Run at State Highway 10.
8. Gravelly Run at Continental Can Road.
9. Bailey Creek at State Highway 10.
10. Bailey Creek below confluence with Cattail Creek.
11. Bailey Creek above confluence with Cattail Creek.
12. Bailey Creek at State Highway 156.
13. Bailey Creek at power line above Sewage Treatment Plant.
14. Drainage ditch at Station Street easternmost crossing.
15. Cattail Creek at State Highway 156.
16. Cattail Creek at power lines.
17. Cattail Creek at sewer line crossing.
18. Corner of LaPrade and Highway 156.
19. Corner of Arlington and Highway 156.
20. Bailey Creek upstream of Sewage Treatment Plant effluent and the seeps below the Kepone Lagoon.
21. Corner of Locust and Dellrose.
22. Dinwiddie Avenue 100 feet southeast of corner of Oaklawn.
23. Corner of Smithfield and Cedar Level.
24. Cabin Creek under Jackson Farm Road.
25. End of West Broadway near the railroad tracks.
26. Riverside Avenue across from the Hopewell Yacht Club.
27. Corner of Brown and Burnside.
28. The Life Sciences Plant site.
29. Corner of 14th and City Point.
30. Same location as Sample 20.

- The Sewer System. Initial sampling in the Hopewell sewer system focused on the sewage treatment plant and on the sewer line connecting it with the Life Science site. This included the Station Street and Main pump stations through which the effluent and runoff from the Life Science plant site were pumped. Samples were taken of the water, slimes, and sludges in these facilities. In addition, raw sewage and slime samples were taken from the 11 pump stations in the Hopewell municipal sewage system through which Life Science effluent and runoff has not flowed. The pump stations of the sewerage system are located in Figure V.6 and listed in Table V.11.

- Follow-up Sampling. Following analysis of samples collected in the initial field study plan, it became apparent that additional sampling would be beneficial. Certain significant findings warranted follow up field sampling in order to establish the magnitude of potential Kepone problems. Additional field work was undertaken at the PAN plant site and the southeast corner of the Hopewell Sanitary landfill.

  At the PAN site, 14 shallow holes were drilled with a hand auger. Samples were collected from the surface and at a depth of 5 ft. Next 8 deep holes were bored to depths between 35 and 50 ft, and samples taken at 1 to 5-ft intervals. Several sediment cores were also collected in the marshy areas around the PAN site. Four sediment cores were taken from the site itself, and 9 cores collected from the Moody's Creek marsh immediately down-flow. A series of runoff samples and several subsurface soil samples using a 10-ft hand auger were also taken.

  Several series of samples were collected adjacent to the southeastern edge of the Hopewell landfill in order to establish the magnitude and transport of highly concentrated Kepone residuals detected in this area during previous sampling. Field work included collection of several 1 to 2-ft cores and 4-in. grabs of sediment to calculate the amount of Kepone residing in this area. Runoff and hand-augered soil samples to depths of 10-ft were gathered to detect any possible transport pattern.

RESULTS AND FINDINGS

Bailey Bay and Tributary Streams

Distribution of Kepone--

The results of sediment Kepone analysis in Bailey Bay and the major tributaries are presented in Figure V.7. Data given represent average concentration of homogenized cores from a depth of 30 cm (12 in.). Kepone was found throughout most of the Bay deposited in a "Y" or yoke shaped pattern.

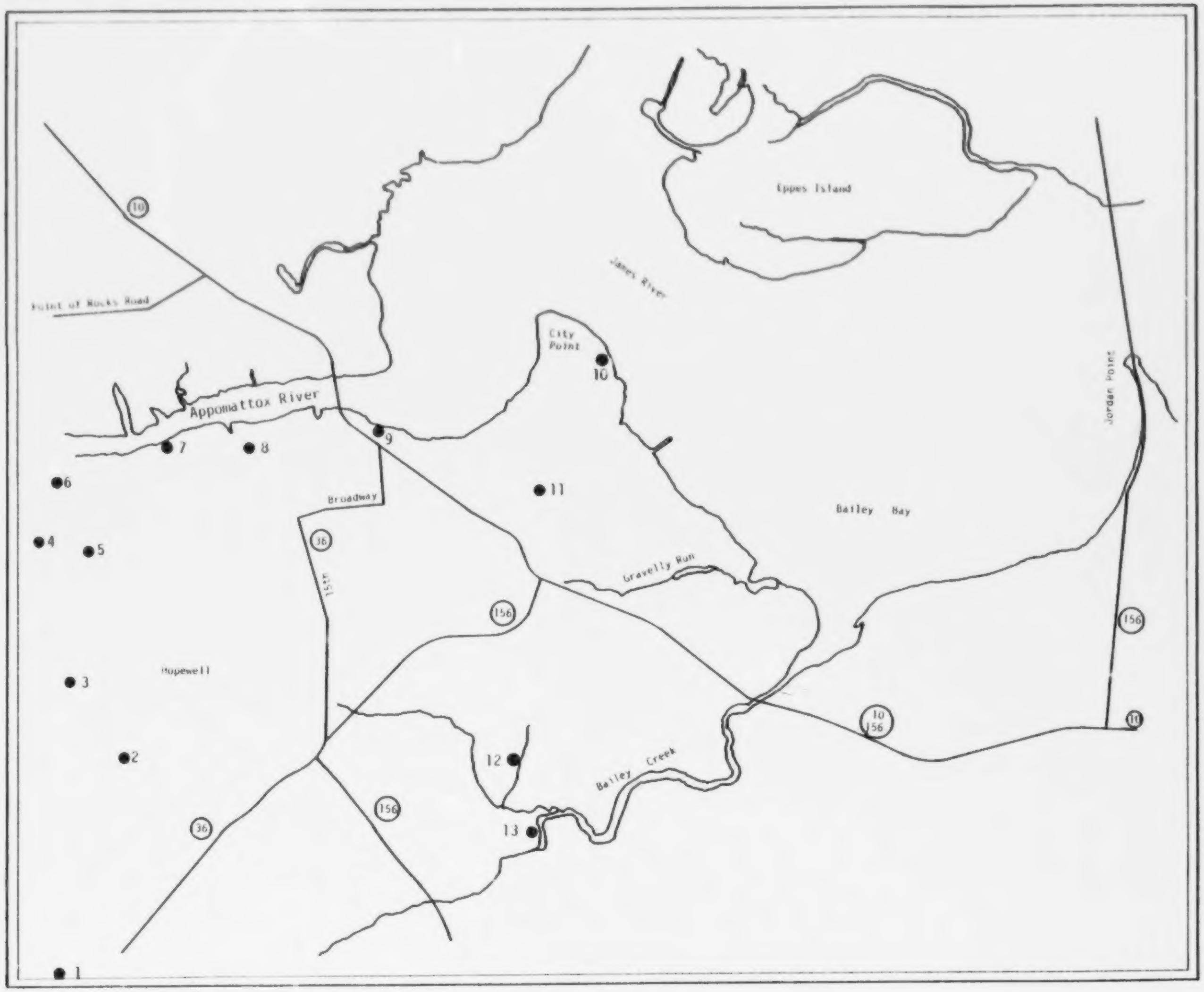

Point of Rocks Road
10
Appomattox River
James River
Eppes Island
City Point
Jordan Point
Bailey Bay
Gravelly Run
Bailey Creek
Broadway
15th
Hopewell
36
156
10 156
1
2
3
4
5
6
7
8
9
10
11
12
13

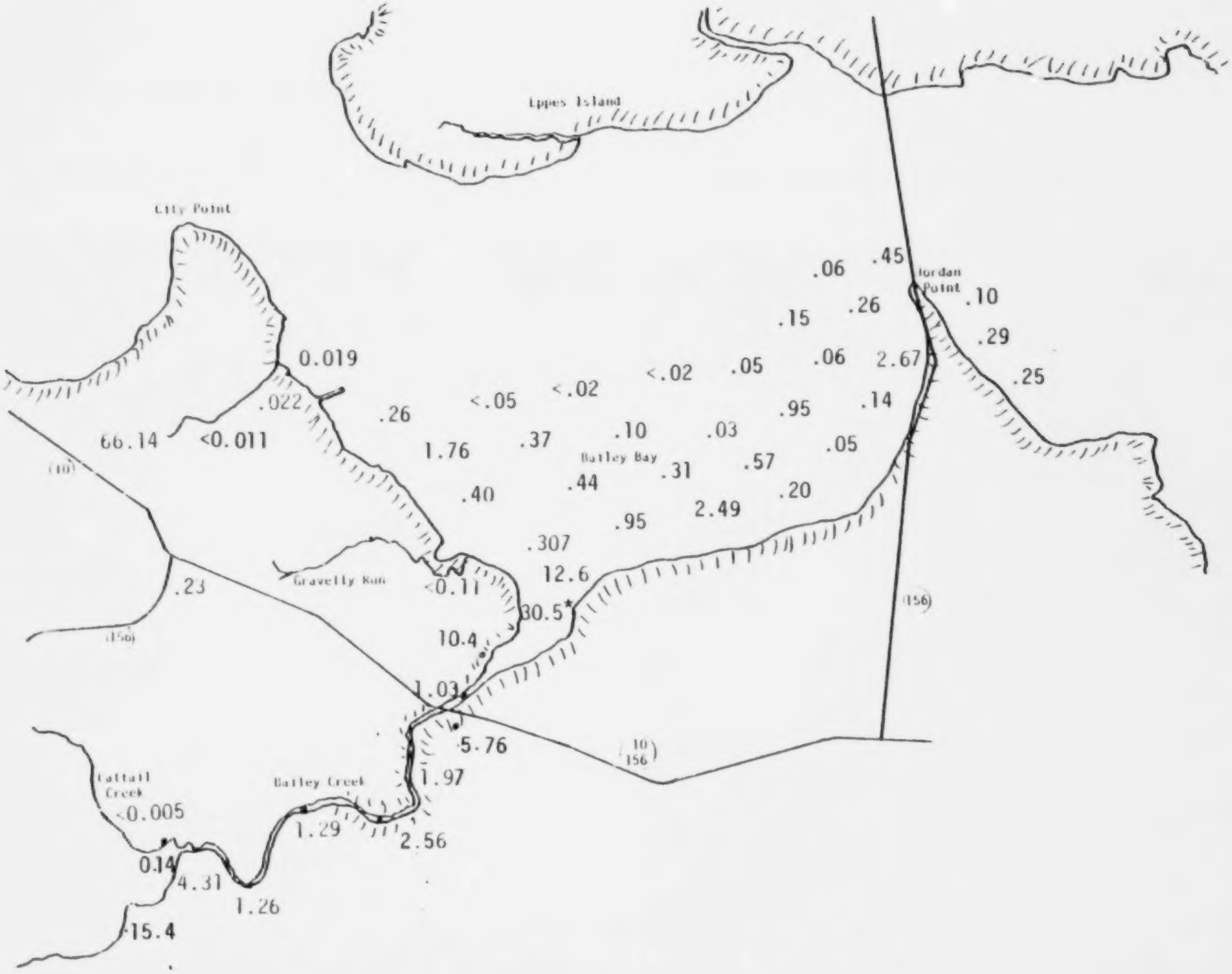
FIGURE V.6. Pump Station Solids and Wastewater Sample Locations

TABLE V.11. PUMP STATIONS LOCATED IN FIGURE V.6

1. Western Street
2. Sherwood Land
3. Sussex Drive
4. Cabin Creek
5. Appomattox No. 1
6. Appomattox No. 2
7. Park Avenue
8. Mansion Hills
9. Sixth Avenue
10. Water Street
11. Station Street
12. Main
13. Bailey Creek

The tail of the yoke begins in Bailey Creek. The arms extend up the eastern and western shoreline of the Bay. The mid-Bay area has a markedly lower overall level of contamination. The deposition pattern coincides with the path of the channel through which Bailey Creek water passes. This was confirmed both by infrared scan of the Bay and visual inspection performed by personnel from NASA during a May 1977 pollutant transport study of the James River. Bailey Creek water is generally dark and easily distinguished from other waters in the Bay. There appears to be little mixing during movement through the Bay so that the line between the two is readily apparent. Under normal outflow conditons the creek water flows along the eastern shore and remains close to the bank as it rounds Jordan Point. NASA personnel observed a reversal of this flow pattern on a calm day with a strong incoming tide. At that time, the creek water turned back at Jordan Point and proceeded to move up the western shore of Bailey Bay until it entered the river proper. This reversal can be seen in the photographs made from NASA remote imagery presented in Figures V.8, V.9 and V.10.

The data in Figure V.7 indicate that Kepone deposits trace the course of movement of Bailey Creek water through the Bay. Cores were also taken from Tar Bay where eddies back from Jordan Point would be expected to occur. Results of the sampling confirmed deposition in this area.


Eppes Island
City Point
Jordan Point
.06
.45
.10
.15
.26
.29
0.019
.05
.06
2.67
.25
<.05
<.02
<.02
.14
.26
.022
.95
66.14
<0.011
1.76
.37
.10
.03
.05
Bailey Bay
.44
.31
.57
.40
.20
2.49
.95
(10)
.307
Gravelly Run
<0.11
12.6
30.5*
.23
(156)
(156)
10.4
1.03
5.76
(10)
(156)
Cattail Creek
Bailey Creek
1.97
<0.005
1.29
2.56
0.14
4.31
1.26
15.4

*167 μg/g Kepone found at 4 in. below surface level

FIGURE V.7. Results of Kepone Analysis in Sediment Cores (μg/g-ppm)

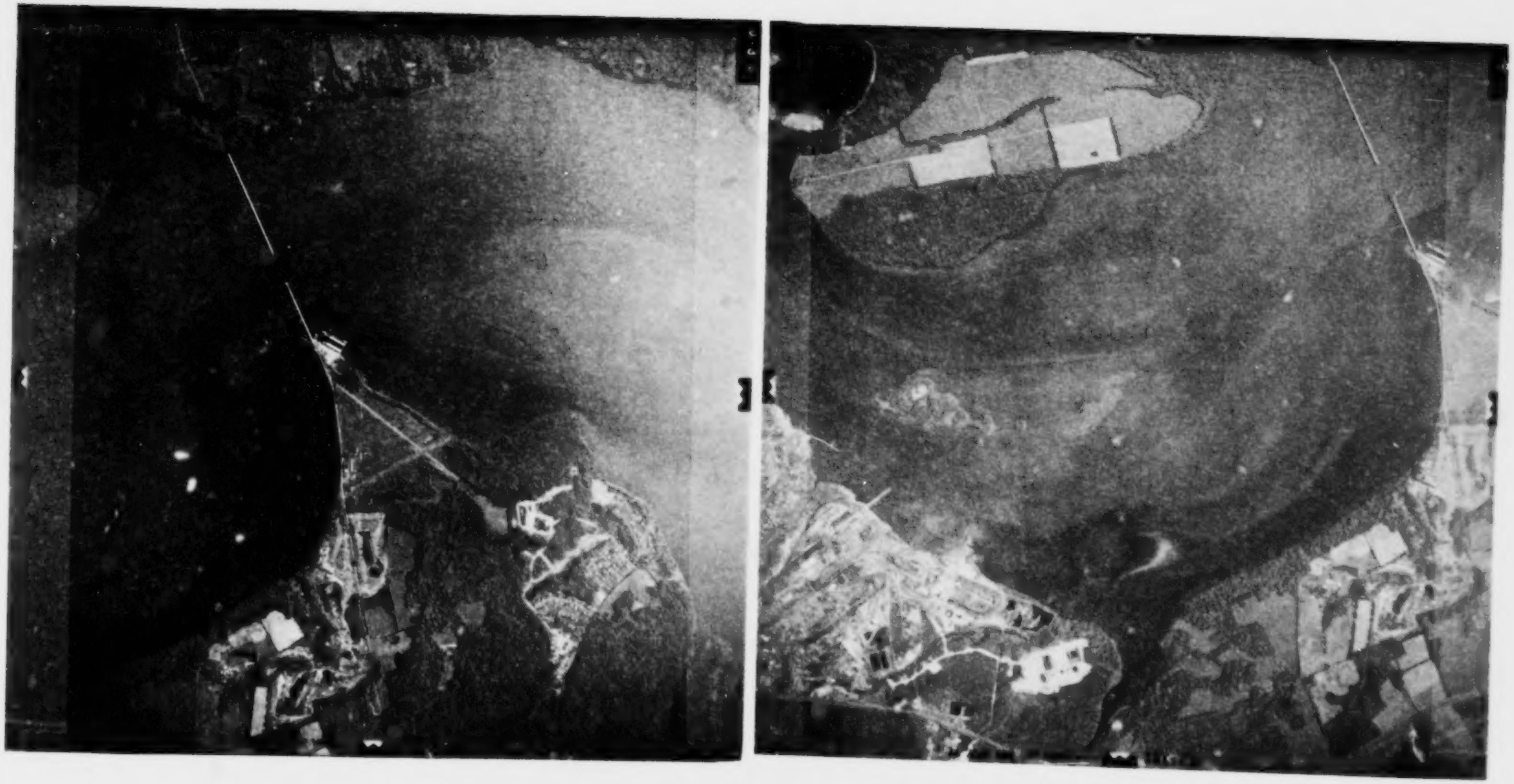


FIGURE V.8. Ebb Flow Conditions Showing Downstream Movement of Bailey Bay Waters (8:30-10:06 A.M. EDT - May 17, 1977)

Photo Courtesy of NASA

Reproduced from
best available copy.

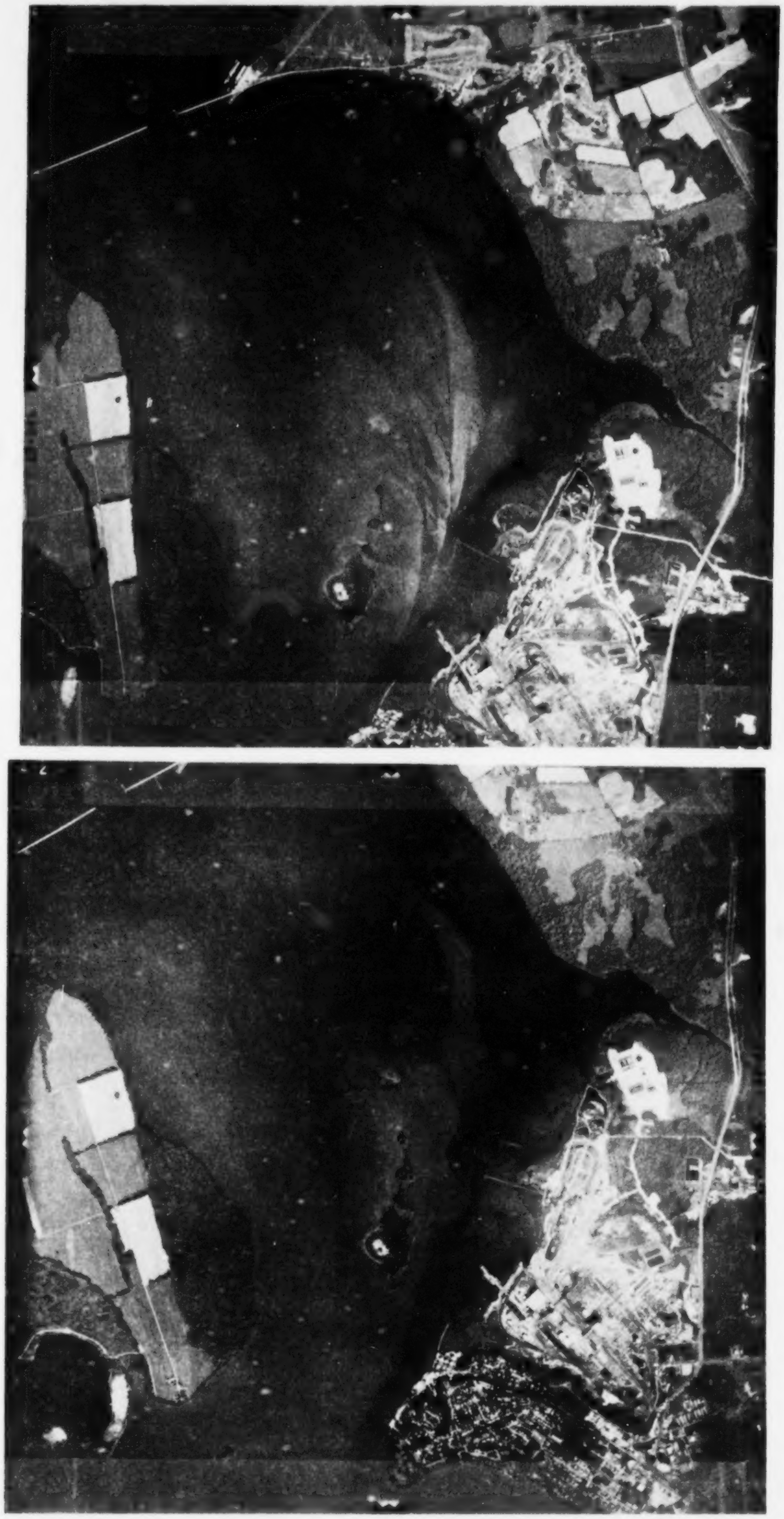


FIGURE V.9. Flow Reversal Observed with the Incoming Tide
(2:45-4:37 P.M. EDT - May 17, 1977)

Photo Courtesy of NASA

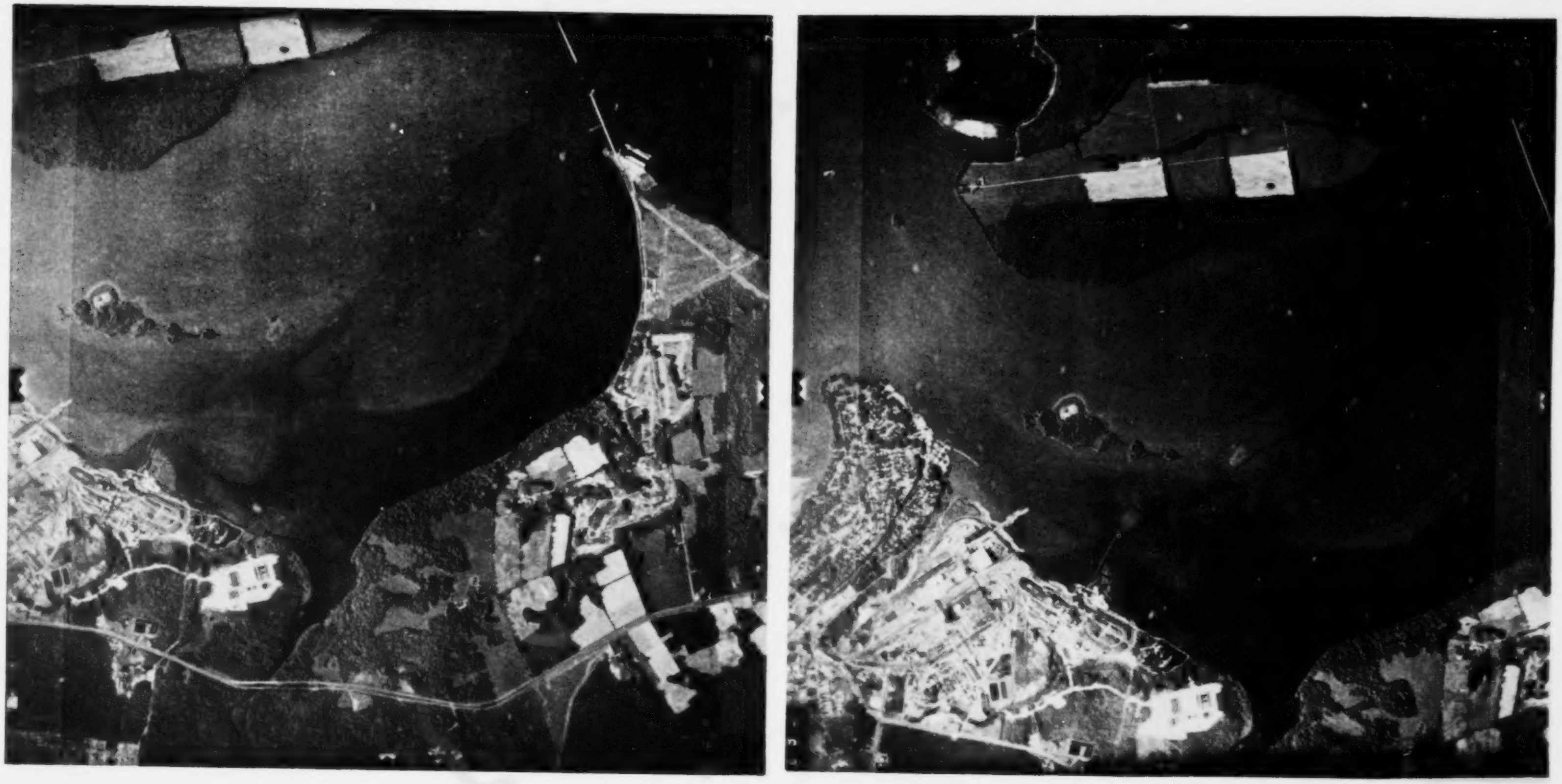


FIGURE V.10. Reconstruction of Normal Downstream Flow Patterns with the Outgoing Tide (5:16-5:37 P.M. EDT - May 17, 1977)

Photo Courtesy of NASA

In comparing current results to early 1976 and late 1976 data from the Virginia State Water Control Board illustrated in Figures III.10 and III.12 it would appear that the zones of high contamination have diminished. The region with 1.0-9.99 μg/g (ppm) Kepone is less than half of what it was in 1976. This is not necessarily borne out by specific data points, however. Some values obtained in the current cores from homogenization of the top 30 cm (12 in.) were higher than values obtained previously along the channel area. The mid-Bay cores do show some reductions in Kepone levels. The implications cannot be fully assessed, however, without first looking at Kepone distribution with depth in the cores.

Kepone concentrations in sediment cores from tributaries to the Bay are also illustrated in Figure V.7. The values obtained in Bailey Creek are relatively uniform except for the 4.31 μg/g (ppm) Kepone found just below the sewage treatment outflow, and the elevated levels at its mouth.

Sediment cores from Gravelly Run which would have received wastewater flows from the Allied Semi-Works plant do not show the elevated levels found in Bailey Creek. The cores from Poythress Run were taken in the path of flow from the region northeast of the Life Science Products plant and from the marsh which receives runoff from Nitrogen Park. No outlets exist at this marsh, and hence the 66.14 μg/g (ppm) Kepone concentration reflects accumulation over time from contaminated runoff as well as possible atmospheric deposition from the production period.

Vertical Distribution in Sediment Cores--

Some insight into scouring and deposition can be gained through review of results from analysis of vertical slices of representative cores. These are presented in Table V.12. The cores from Bailey Creek, the western shore, and Jordan Point display a bell-like distribution presumably reflecting increasing Kepone deposition rates during maximum production and subsequent declines since the closure of the Life Science Products plant. The cores from mid-Bay and Tar Bay, areas of low deposition, have high surface contamination levels which rapidly decline with depth. Consequently, newer, less contaminated sediments have not yet accumulated to a sufficient extent to cover over the older ones. If it is maintained that the bell distribution is derived solely from new deposition, it would constitute an excessive rate of deposition which could not be sustained. On the other hand, if the area is subject to periodic scour and deposition with uncontaminated sediments, a similar dilution could occur with no net change in overall sediment depths. The distribution could also reflect losses of Kepone through desorption. The flowing water would in effect be extracting Kepone and carrying it downstream. Such a bell-like curve can be indicative of this type of loss mechanism and corresponds well with data in Chapter VII on the James River when 65 to 70% of all Kepone movement was found to result from soluble Kepone. This would also explain the relative absence of Kepone in Gravelly Run which has contained high flows of uncontaminated water since Kepone production ceased at the Allied Semi-Works plant. When the values in Figure V.6 are extrapolated across the bed of Bailey Creek and Bailey Bay, they suggest a current Kepone burden of 540 kg (1200 lb) based on mean concentrations.

TABLE V.12. KEPONE DISTRIBUTION IN SEDIMENT CORES WITH DEPTH (ppm) (NOTE: DETECTION LIMITS IN SEDIMENTS VARIES WITH SAMPLE SIZE AND THE PRESENCE OF OTHER MATERIALS)

Depth from Surface (in.)	Bailey Creek Above Route 10 Bridge	Bailey Creek Mouth #1	Bailey Creek Mouth #2	Gravelly Run Mouth	Midway Poythress and Gravelly Runs	Mid Bay	Bailey Bay Jordan Pt.	Tar Bar Jordan Pt.
1	0.81	1.36	9.44	<0.34	0.11	0.19	0.95	1.09
2	0.59	1.66	10.55	<0.10	0.13	0.03	0.86	1.27
3	1.30	2.54	46.53	<0.05	<0.08	0.03	0.87	0.42
4	0.78	3.88	167.0	<0.09	0.15	0.01	0.87	0.03
5	16.46	14.07	102.0	<0.09	0.92	0.01	1.25	0.02
6	2.91	40.74	18.34	<0.10	0.80	0.03	3.63	<0.01
7	65.14	42.29	5.12	<0.06	0.30	<0.01	17.80	<0.01
8	19.17	13.87	0.55	<0.06	<0.04	<0.01	0.17	<0.02
9	0.90	4.34	0.41		<0.03	<0.01	0.16	<0.01
10	0.45	0.86	0.37		<0.03	<0.01	0.14	<0.02
11		<0.51	0.31					
12		<0.42	0.36					
13		<0.19	0.38					
14		<0.10	0.14					
15		<0.14						
16		<0.04						

Desorption is a slow process. The affinity of Kepone for sediments over water will dictate that only a minor fraction of the total inventory can be released at any one time. However, this process may be accelerated in Bailey Bay by high pH waters from industrial discharges. Sampling in Bailey Creek revealed stream flow pH levels of 8.5 to 11 at various times during the day (see Chapter VI). As noted earlier, Kepone solubility increases greatly with elevated pH and desorption is accelerated. Hence, the chemical quality of Bailey Creek water may well have stimulated rapid desorption which yielded the bell distribution found in vertical cores. Routing of industrial wastes to the regional treatment plant will minimize the occurrence of high pH conditions in the future. Hence, desorption is likely to slow down.

Organic Preference--

When selected sediments (for location see Figure V.3) were subjected to grain size and Kepone analysis, they yielded the results presented in Table V.13. From these, there is a general relation between Kepone concentration, organic content, and particle size. Kepone is apparently preferentially associated with the larger particles of organic origin in the sediment. This observation coincides with those made by Allied Chemical (Williams, 1977) and Virginia Institute of Marine Science (Huggett et al., 1977) and suggests that detrital matter plays an important role in the binding and transport of Kepone. The work reported by Huggett is of special interest since uncontaminated particles of rooted aquatic plants were found to rapidly accumulate Kepone to 2.4 μg/g (ppm) when suspended in the James River at the Benjamin Harrison Bridge where soluble Kepone concentrations were below the level of detection.

At first glance, the relation between Kepone and loss on ignition in Table V.13 does not appear to be direct. However, it must be noted that with loss on ignition there is also a loss of inorganic carbonates. If these are accounted for, the relation between Kepone and organic content is approximately linear. This also corresponds very well with theoretical and empirical observations on partitioning between water and sediments discussed in Chapter IV on Kepone properties.

Toxicant and Heavy Metal Content--

Results of heavy metal analysis of sediment cores (for location see Figure V.3) are given in Table V.14. With reference to the sample from the upriver station (above the confluence of the Appomattox) all Bailey Bay samples show higher levels of inorganic contamination (except for the mid-Bay chromium value which is slightly lower). The Jordan Point and upriver samples for antimony are roughly equivalent. The antimony values are of interest since antimony pentachloride was employed as a catalyst in the Kepone production process. Previous analyses revealed up to 100 mg/ℓ (ppm) antimony in effluent from the Life Science Products plant (Senate Hearings, 1976). The information available on production chemistry reveals a use ratio of 25:7600 antimony to Kepone. At this ratio, the sediment areas with 15 μg/g (ppm) Kepone would hold only 0.049 μg/g (ppm) antimony, a level below the detection limit in the analyses employed here. The data point for the mouth of Bailey Creek, therefore, constitutes a level in excess of what would be predicted solely on the basis of reaction quantities. The high level of antimony at mid-Bay demonstrates a lack of proportionality between Kepone and antimony concentrations when sites are compared.

TABLE V.13. DELINEATION OF GRAIN SIZE AND KEPONE CONTENT IN BAILEY BAY SEDIMENTS

Sample Location	Particle Size	Fraction of Total Sample (%)	Kepone Concentration µg/g (ppm)	Fraction of Total Kepone In Sample (%)	Loss On Ignition 500°C (Organic Content)%	µg Kepone per g Organic
Jordan Point	Silt	48	0.37	11	10	1.76
	Sand	22	5.65	80	52	2.4
	Clay	30	0.47	9	15	0.95
Mid Bay	Silt	47	0.08	35	6	0.66
	Sand	25	0.25	58	13	0.48
	Clay	28	0.03	7	25	0.034
Mouth Bailey Creek	Silt	69	11.74	65	15	53
	Sand	18	19.82	29	52	11
	Clay	13	5.61	6	17	4.29

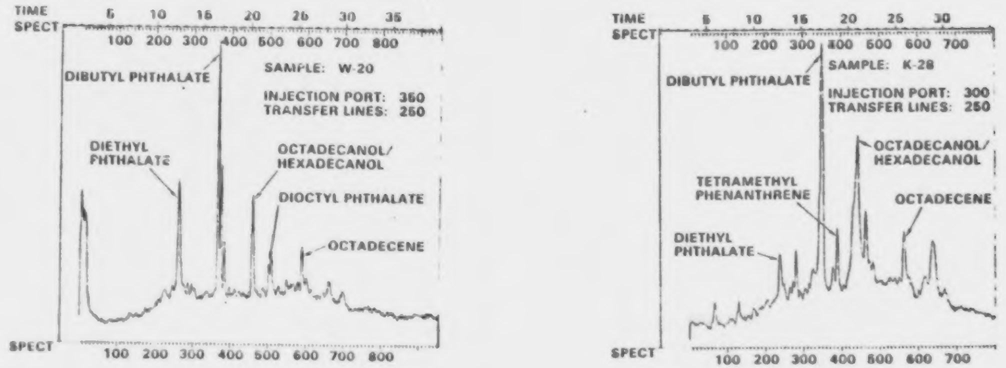
TABLE V.14. TOXICANT AND HEAVY METAL CONTENT OF BAILEY BAY SEDIMENTS (μg/g-ppm)

Location	Antimony (Sb)	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Lead (Pb)	Mercury (Hg)
Mouth of Bailey Creek	13	<4.5	1.31	172	172	0.37
Mid-Bay	13	<1.7	0.66	83	57	0.19
Jordan Point	1.8	<2.0	1.08	82	71	0.34
James River upriver from confluence of Appomattox	2.8	<1.6	0.52	69	20	0.12

The significant levels of chromium and lead in the Bailey Creek sediments cannot be related directly to Kepone production. They are of interest, however, since they could potentially be toxic to aquatic life if released during efforts to remove Kepone. They may also restrain recovery of Bailey Bay for viable, diverse aquatic communities even after amelioration of the Kepone contamination.

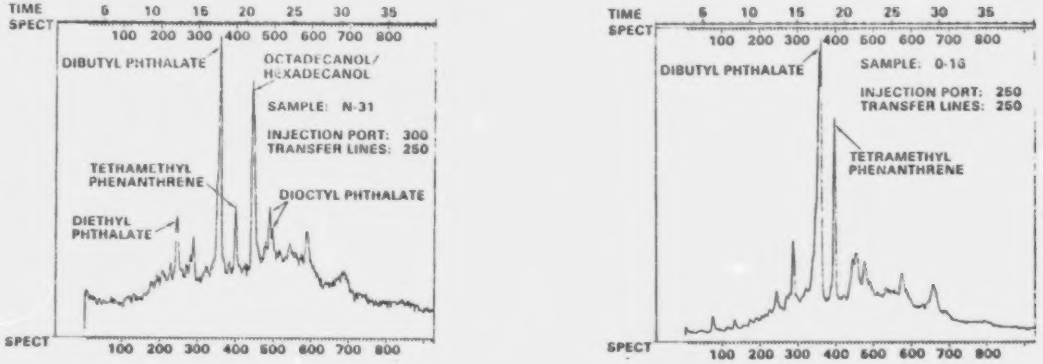
The reported values for mercury and cadmium compare closely to those reported by the Corps of Engineers during the same period. The lead values are higher. The Corps data reveal lead concentrations of 13 to 37 μg/g (ppm) in the Bay. The Corps also reported copper in the range 2 to 25 μg/g (ppm) and zinc at 130 to 716 μg/g (ppm) (Jennings, 1977). Should these metals be biologically available, the removal of Kepone from the Bay may not restore its viability as an aquatic habitat until this contamination is mitigated as well.

The spectra for the GC/MS analysis of the concentrated hexane extracts of four wet sediment samples from Bailey Bay are shown in Figure V.11. (No additional organic materials were identified in the toluene:ethyl acetate, the petroleum ether:ethyl ether, or the acetone:hexane extracts of the dried and ground sediments.) The major components in all four samples were phthalates. These included diethyl, dibutyl (the most abundant compound in each of the samples), and two dioctyl phthalates. These identifications were made by comparison of the experimental spectra with spectra published on the Mass Spectrometry Data Center Eight Peak Index of Mass Spectra. Using this collection of spectra, other compounds which were tentatively identified in the samples were octadecanol or hexadecanol, octadecene and a C4 phenanthrene which had a spectrum very similar to that of tetramethylphenanthrene. No other phenanthrenes were found in the samples.



1. James River above Hopewell.

2. Mouth of Bailey Creek.



3. Mid Bailey Bay.

4. Jordan Point, Bailey Bay.

FIGURE V.11. GC/MS Analyses of Bailey Bay Sediment Extracts

The location of organic contaminants displayed varying patterns of distribution depending on the compound. The diethyl and dioctyl phthalates appear to come from a source upriver of Hopewell. The octadecene appears in both the upriver and Bailey Creek samples but not in the Bay. Dibutyl phthalate is relatively ubiquitous. Octadecanol/hexadecanol appears both upriver and in Bailey Creek. Tetramethyl-phenanthrene is found only in Bailey Creek and Bay. Hence, contaminants in the Bailey Bay area are not all attributed to sources in Hopewell. Some could result from discharges upriver of Hopewell. The data are not definitive, however, since tidal action may carry contaminants from Hopewell back upriver. These compounds may produce environmental stress as a result of their presence. In some isomeric forms they are characterized by oral LD_{50} values of 4 to 140 mg/kg body weight to rats and LC_{50} values of 1 to 32 μg/ℓ (ppm) to bluegill and fathead minnows.

The Hopewell Area

The Sewer System--

Analysis of samples taken from the city of Hopewell primary sewage treatment plant in May and July are consistent with the results compiled by Hopewell (see Chapter III). Influent Kepone levels were measured at 0.77 and 0.44 μg/ℓ (ppb) and the effluent contained 0.57 and 0.49 μg/ℓ (ppb) Kepone. It is clear that Kepone was either never completely cleaned from the system or is still entering the Hopewell sewerage system and subsequently being discharged in treatment plant effluent. Recent levels of 0.5 μg/ℓ (ppb) account for an average Kepone effluent discharge of $0.5\ \mu g/\ell \times 3 \times 10^6$ gdp $\times 3.79\ \ell/gal =$ 5.69 g/day. Higher Kepone concentrations are seen to occur periodically, Table V.15, as a function of precipitation. During periods of high runoff, daily Kepone discharges were found to be 37.6 g. This is over six times the dry weather contribution. The effluent from the primary treatment plant now flows to the new regional treatment plant where Kepone may well be removed through sorption on sludge. Consequently, the above calculated inputs of Kepone to the River may be reduced or eliminated.

Surveys of major sewer trunklines were conducted to determine the geographical distribution of Kepone inflow sources. Results of these investigations are presented in Figure V.12. Wastewater and slime from all pump stations and manholes tested were found to have measurable Kepone concentrations. It should be noted that the Station Street area is the only sector served by combined storm-sanitary sewers.

The July 28 sampling was performed during dry weather conditions. It is noteworthy that Kepone occurs in all samples with the possible exception of the Appomattox pump station where the reported value is at the limit of detection. Secondly, the Life Science manhole is upstream of the Station Street pump station. Therefore, the manhole data (1.73 μg/ℓ-ppb) are accounted for after dilution with the Station Street sample (0.22 μg/ℓ).

TABLE V.15. DAILY VARIATION IN KEPONE CONTENT OF SEWAGE AND PRECIPITATION AT HOPEWELL PRIMARY TREATMENT PLANT

		Kepone in Sewage Treatment Plant (μg/ℓ-ppb)			
Date	Time	Influent	Effluent	Precipitation (in.)	Flow (MGD)
8/2/77	1615	0.18	0.45		
8/4/77	1130	0.15	0.68		
8/5/77	1100	0.14	0.17		
8/6/77	1600	0.15	0.73		
8/7/77	1530	0.26	0.76		
8/10/77	1200	0.25	0.46	0.0	
9/7/77	1100	3.49	2.63	1.3	3.83
9/8/77	1100	4.88	2.32	0.4	3.71
9/16/77	1100	0.21	0.29	0.9	3.27
9/28/77	1100	0.11	0.30	0.0	2.90
2/3/78	1100	0.36	0.42		

The dilution factor represented here coincides with data from May 19, 1977, when effluent from the Life Science plant area registered 2.57 μg/ℓ (ppb) Kepone and wastewater at the Station Street pump station was found to carry 0.38 μg/ℓ (ppb) Kepone. That is an average dilution of 7.5:1. The sewage from the Station Street pump house carried insufficient Kepone to account for the levels during that period (July 18, 1977) at the Main pump station: 0.44 μg/ℓ (ppb) Kepone. Similarly, none of the four pump stations sampled carried a high enough concentration of Kepone to account for the levels measured in the treatment plant influent. Clearly a more comprehensive sampling was required including all pump stations.

A second survey was conducted on all pump stations on September 19, 1977. These results are also illustrated in Figure V.12. From these data, the apparent anomaly of the Main pump station is solved. Several tributary trunklines were found to carry sufficient Kepone concentrations to account for the levels in the composite flow at the Main pump station. In particular, high values for Kepone were found in wastewater from the Western Street (#1), Appomattox No. 1 (#5), Appomattox No. 2 (#6), and the Sixth Avenue (#9) pump stations (see Figure V.6). Comparison of the July 28 and September 15 data reveals little change in wastewater Kepone concentrations except for the

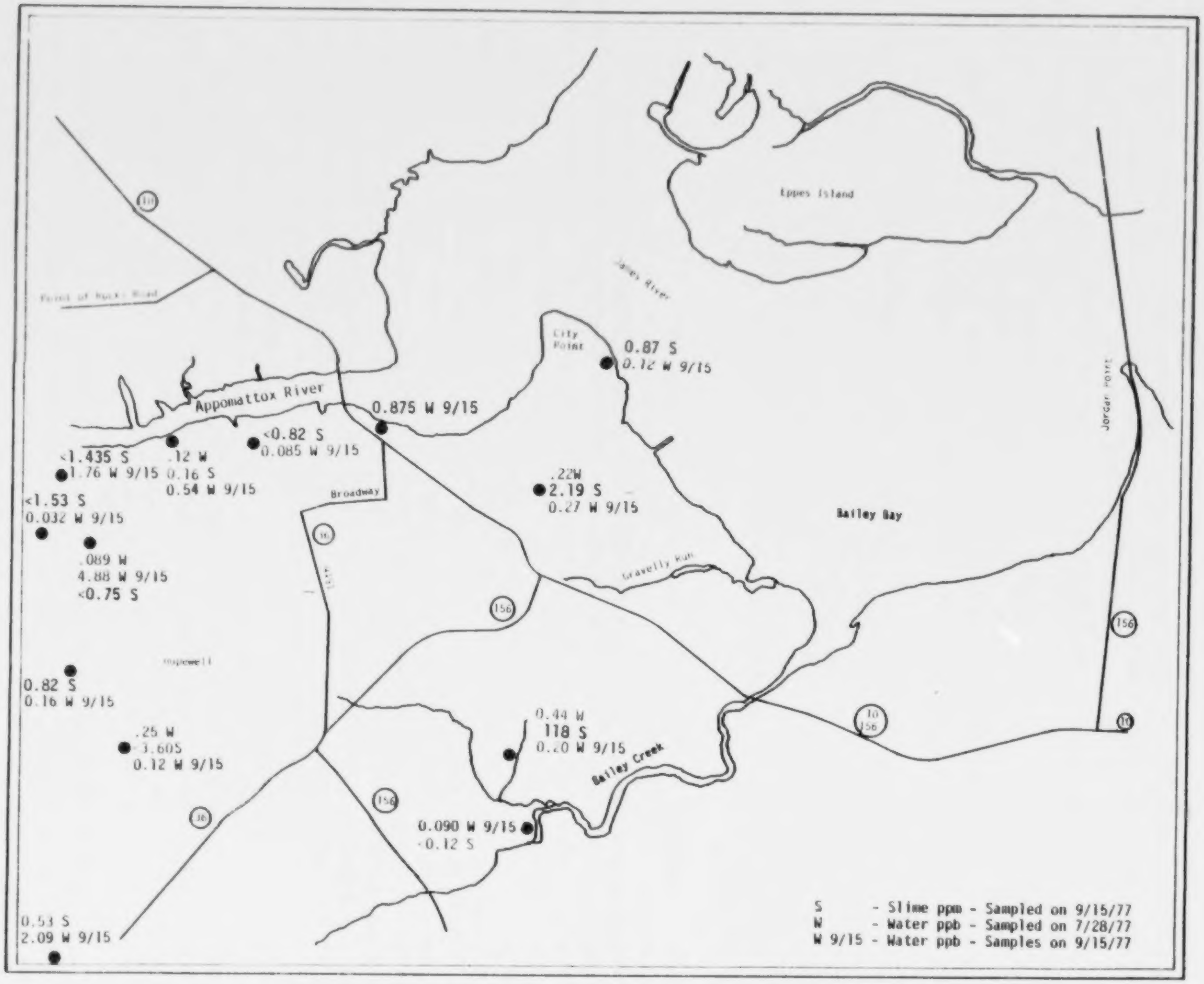

Eppes Island
James River
City Point
0.87 S
0.12 W 9/15
Jordan Point
Point of Rocks Road
Appomattox River
0.875 W 9/15
<0.82 S
0.085 W 9/15
<1.435 S
1.76 W 9/15
.12 W
0.16 S
0.54 W 9/15
Broadway
.22W
2.19 S
0.27 W 9/15
Bailey Bay
<1.53 S
0.032 W 9/15
.089 W
4.88 W 9/15
<0.75 S
Gravelly Run
156
36
10
Hopewell
0.82 S
0.16 W 9/15
.25 W
3.60S
0.12 W 9/15
0.44 W
118 S
0.20 W 9/15
Bailey Creek
10
156
0.090 W 9/15
<0.12 S
0.53 S
2.09 W 9/15
S - Slime ppm - Sampled on 9/15/77
W - Water ppb - Sampled on 7/28/77
W 9/15 - Water ppb - Samples on 9/15/77

FIGURE V.12. Kepone Concentration in Sewage Solids and Wastewater

Appomattox No. 1 pump station where the sewer sampling reveals a level almost 2 orders of magnitude higher than the original sampling. No explanation for this is readily apparent.

Some data pertinent to this are available. Solids were scraped from the walls of the wet wells at the various pump stations, and the wet well at the Main pump station. These were found to contain the values presented in Figure V.12. Kepone is present in seven of the thirteen wet wells. A particularly high level [118 μg/g (ppm) Kepone] was detected at the Main pump station. It is hypothesized that the Kepone present was adsorbed or otherwise accumulated by the slime from inflows during the production periods of 1974-1975. Currently, these deposits help maintain the levels of Kepone found in wastewater. This may occur when Kepone-contaminated growth breaks away from the walls and enters the sewage as suspended solids or through desorption.

The high concentrations found in sewer solids suggest that Kepone movement down the system is not directly responsive to fluctuations in Kepone entry to the sewer system in the first place. Evidence suggests a buffer action over the long term which smooths out erratic imputs to relatively stable effluent levels. Anomalies are also likely to be associated with difficulties in obtaining a "representative" sample of sewer solids at any point in time.

The apparent continued contamination of most sewer lines and not just those served by combined storm sewers raises the issue of where Kepone residues originated from. As noted in the preceding discussion, the Kepone in wastewater is believed to derive from residuals in slime growths and solids in the system. The solids are therefore thought to be acting as reservoirs which collected Kepone during 1974-1975 and are now slowly releasing it. Some lines may have been contaminated by batches of waste dumped into manholes. It is further believed that an additional source of Kepone to these diverse pump stations was physical transport of dust on workers' clothes and bodies. The contamination was subsequently washed into the sewers and absorbed by attached growths. While this mechanism of transport would appear insignificant some supportive data do exist. Former employees have noted that they often returned from work covered with a fine layer of Kepone dust. In testimony at the Senate Hearings on Kepone contamination, Mr. Thurman Dykes noted that he would have Kepone dust all over his clothes and skin after an 8-hr shift (Senate Hearing, 1976). While Mr. Dykes changed his clothes at the plant, he like many employees took them home and washed them nightly. It has subsequently been reported that Mrs. Dykes and the couples' daughter developed a skin rash when their clothes were washed with the work clothes. They both also have subsequently been found to have detectable levels of Kepone in their blood.

During the Battelle studies, a former employee of Life Science Products was contacted to determine the likelihood of Kepone transport in clothes and subsequent uptake in pipeline slime. It was determined that work clothes had been laundered at home, and that the washing facilities were served by a separate drainline routed to a nearby drainage ditch. Analysis of slime deposits in this pipe taken on September 28, 1977 revealed 21.4 μg/g (ppm). Sediments in the drainage ditch contained 1.07 μg/g (ppm) Kepone.

While Kepone-contaminated slime and solids in the sewer lines appears to account for much of the Kepone subsequently found in treatment plant effluent, it does not constitute a major reservoir of Kepone residuals. For purposes of quantifying Kepone levels in the sewer system, a preliminary design estimate was made of the length and diameter of trunklines in the Hopewell area. (Precise data were lost in a fire, and no system design estimates are currently available.) As a result of that estimation process, it was calculated that as much as 13,000 m of 38-cm (18,700 ft of 15-in.) pipe, 550 m of 61-cm (1800 ft of 24-in.) pipe, and 730 m of 81-cm (2400 ft of 32-in.) pipe may be included in current trunklines. Based on this estimate and an assumed slime thickness of 0.64-cm (0.25 in.) the system contains some 117.5 m^3 (4148 ft^3) of slime or roughly 183,300 kg (414,800 lb). If the average Kepone concentration in these lines is 1 µg/g (ppm), this would constitute a total inventory of only 0.11 kg (0.24 lb) of Kepone in the trunklines. This is not sufficient Kepone to have sustained effluent levels that have been observed with time, since daily discharges in dry weather include 6 g of Kepone. At that rate, the sewers would be depleted in 30 days. Therefore, much larger stores of Kepone must be present in collector lines and/or additional Kepone must enter the sewer system from runoff and leachate. It is estimated that these deposits will account for less than 22.7 kg (50 lb) of Kepone. Without outside inputs, these deposits should be depleted soon with a subsequent reduction in Kepone concentrations in sewage plant influent.

Production Area Runoff--

Regardless of the mechanisms involved, Kepone continues to enter the Hopewell sewerage system. As noted earlier, there is evidence that suggests some of the inputs are tied to precipitation and resulting runoff. The obvious site of such inputs would be the Life Science Products plant area where soil contamination was heaviest and the only neighborhood where the storm sewers are combined with domestic sewers. Sampling was conducted at that site on May 4, 1977, when 5.8 cm (2.3 in.) of precipitation fell in Hopewell. Location of runoff samples collected at the Life Science Products plant site and resulting Kepone concentrations are reported in Figure V.13.

Both samples RO-1 and RO-3 were heavily contaminated and represented runoff which moved directly to the storm sewer system. No data are available with respect to the state of the Kepone, i.e., contaminated particulates or dissolved. Hence, it is uncertain whether Kepone is present in runoff as a function of soil suspension or leaching action. At a nominal pH of 4.5 for rainwater (typical value for industrialized areas as reported by Esman and Fergus, 1976), Kepone is soluble up to 1.75 mg/ℓ (ppm). The presence of the soil, however, will reduce soluble levels until an equilibrium is reached. If the partition coefficient approaches 10^{-4} (concentration in water to concentration in soil), this suggests that maximum soluble levels over soil could approach 400 µg/ℓ (ppb) only if soil concentrations approached 4 mg/g (ppth) Kepone. As noted in subsequent sections, no soil samples have been found with concentrations that high. Three soil samples in this area were found to contain 9.51 (Life Science plant site), 86.9 (NW railroad yard), and 208 (Nitrogen Park) µg/g (ppm) Kepone. When these were allowed to reach equilibrium in the presence of distilled water, the centrifuged supernatant contained 604, 145, and 112 ppb Kepone, respectively. This suggests that much of the Kepone found is not sorbed to the soil but is present as Kepone particles which can be dissolved by rainwater and transported during periods of surface runoff. This coincides with the fact that deposition in these areas was from atmospheric fallout of particulate Kepone.

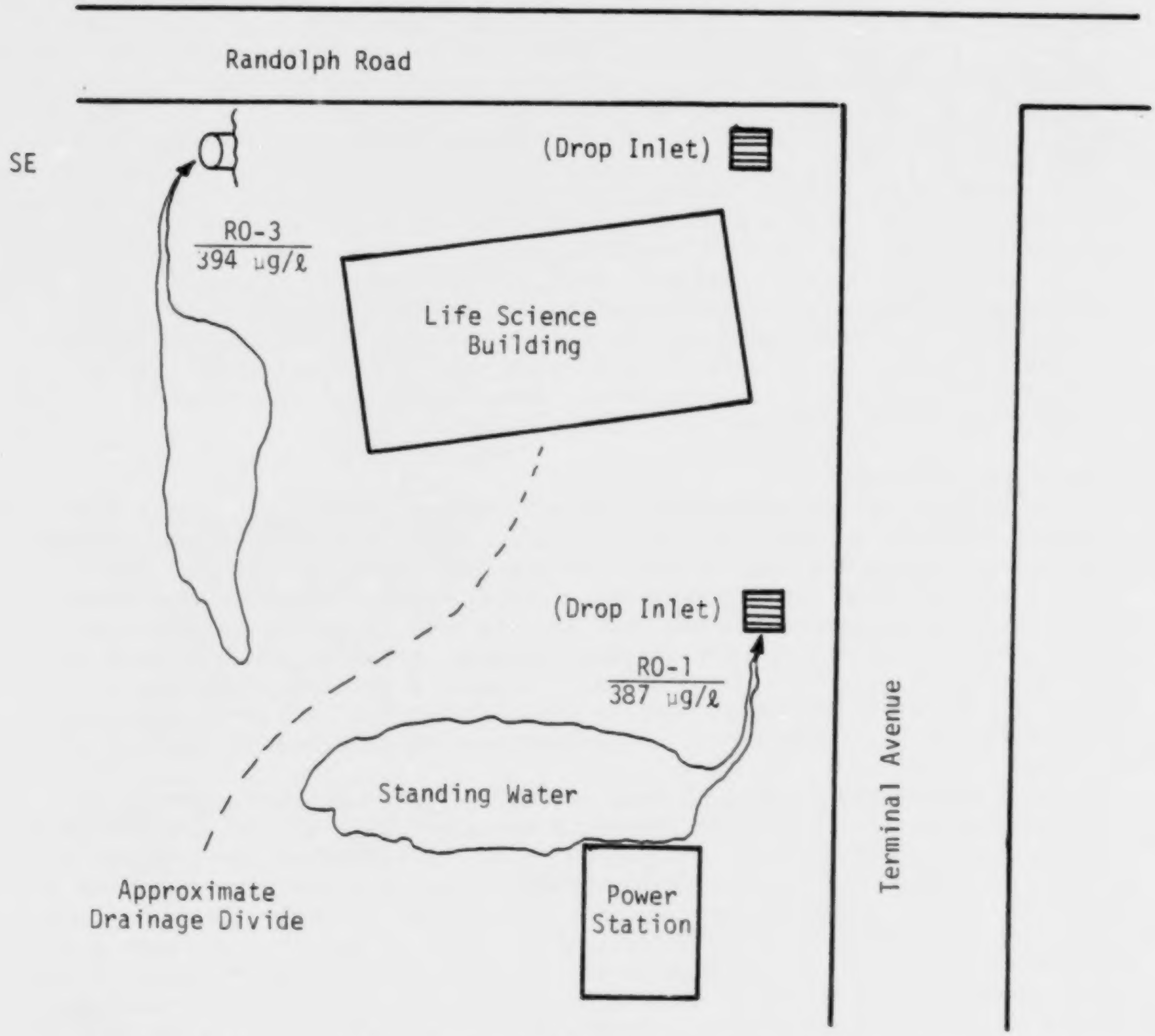

Randolph Road
SE
(Drop Inlet)
RO-3
394 µg/ℓ
Life Science Building
(Drop Inlet)
RO-1
387 µg/ℓ
Standing Water
Power Station
Approximate Drainage Divide
Terminal Avenue

FIGURE V.13. Location of Runoff Samples at Life Science Company Plant

A second detailed sampling of overland runoff was conducted in the open areas around the former Life Science Products plant site. Sample locations and sites are indicated in Figure V.14. These data amplify the fact that high levels of Kepone occur in runoff from the Life Science Plant area. They also suggest that elevated Kepone runoff levels correspond with soil values reported for the Station Street neighborhood.

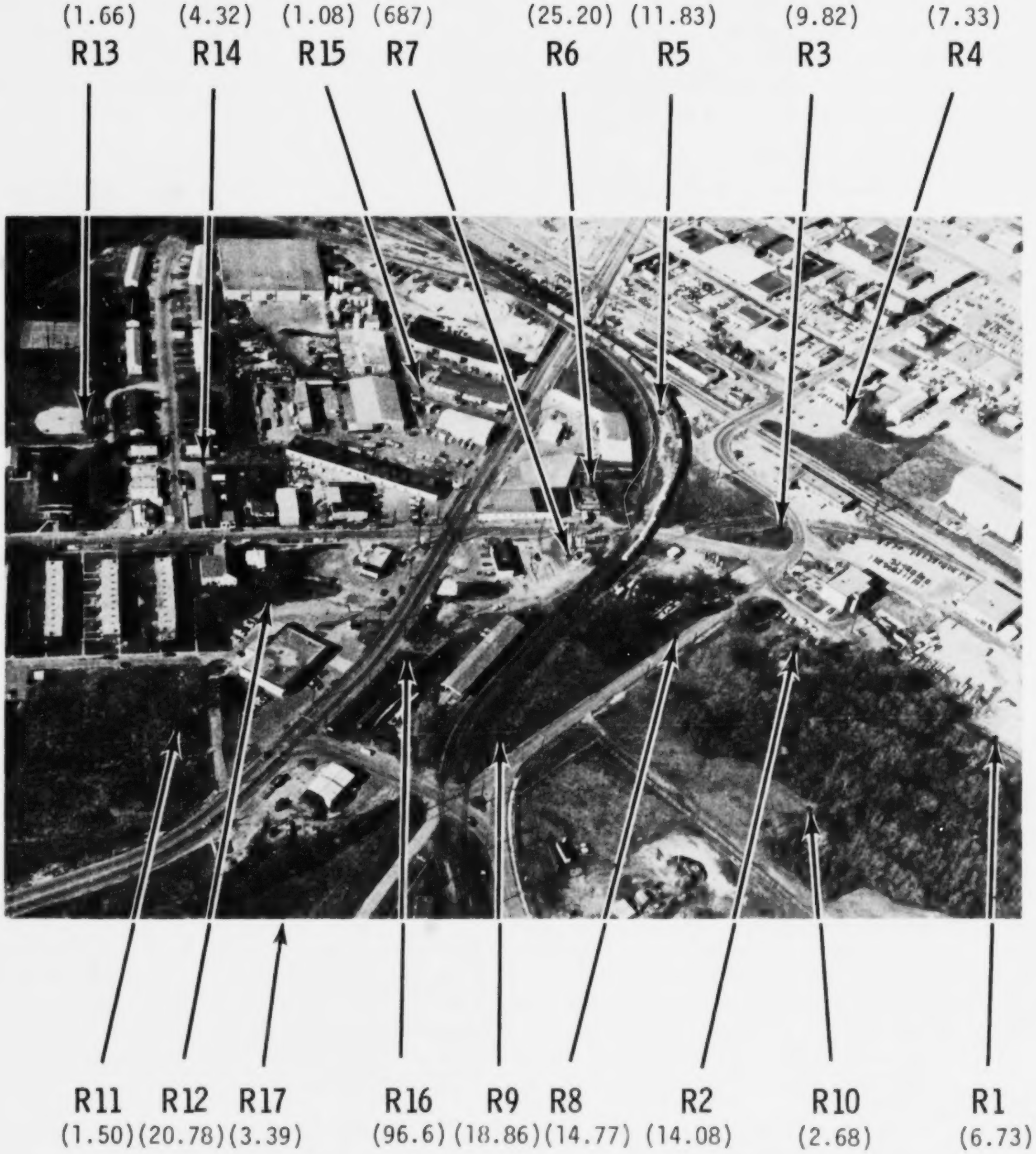

(1.66)
R13
(4.32)
R14
(1.08)
R15
(687)
R7
(25.20)
R6
(11.83)
R5
(9.82)
R3
(7.33)
R4
R11
(1.50)
R12
(20.78)
R17
(3.39)
R16
(96.6)
R9
(18.86)
R8
(14.77)
R2
(14.08)
R10
(2.68)
R1
(6.73)

FIGURE V.14. Runoff Sampling Locations and Kepone Concentrations in Open Areas Around the Life Science Site November 29, 1977 (μg/ℓ-ppb)

Runoff samples were also collected in the area of the Allied Semi-Works plant. On August 7, 1977, after a rainfall of 0.25 cm (0.1 in.) standing water was found to contain 48.3 μg/ℓ (ppb) Kepone. The runoff water is not carried off by storm sewers to the sewage treatment plant; rather, it flows to Gravelly Run. A nearby drain pipe was found to carry 3.38 μg/ℓ (ppb).

Overland Runoff--

Runoff will affect far more than Kepone levels in sewage. As noted earlier, the majority of the land mass in and around Hopewell is not served by combined storm and sanitary sewers. Hence, runoff in these areas will follow storm lines and natural drainage routes and ultimately enter the creeks and runs which feed the James. To estimate the effect of runoff on Kepone movement, a series of water samples were taken along creeks in the area during low flow (May 19, 1977) and runoff conditions (May 16, 1977 and October 3, 1977). The results of subsequent Kepone analysis are presented in Figure V.15.

In all cases, runoff conditions increased the total Kepone concentration over that observed during low flow with the possible exception of the mouth of Gravelly Run where both samples were extremely low. The flow at the mouth is predominantly made up of cooling water from the Allied plant (100 MGD) drawn from the James River. The levels of Kepone are close to those found in the River and probably reflect the recycle of Kepone rather than new inputs, hence, only the 0.28 μg/ℓ (ppb) noted above the Allied discharge is new Kepone to the river system. The progression of Kepone concentrations with movement downstream is also of interest. In Bailey Creek, Kepone levels increase from the Highway 156 crossing to a point just upstream of the confluence of Cattail Creek. Especially high Kepone concentrations were found in the area where landfill runoff and seeps near the disposal lagoon enter Bailey Creek. The same increase in Kepone with movement downstream is true of Cattail Creek itself.

A second set of Bailey Creek water samples was collected on January 12 and 13, 1978 to further delineate the circumstances surrounding transport in that area. The results of subsequent analysis are compared with earlier data and concomittant conditions in the Creek in Figure V.16. Once again, highest Kepone concentrations occur on days when runoff is heavy. At the mouth, the effect is most notable during slack tide. The 1/12/78 flood sample at the mouth suggests carry back from Bailey Bay does affect Kepone concentrations. The effect of pH level cannot be fully assessed. The high pH values were all found near the mouth and consequently the high Kepone levels in that same area may reflect higher solubilities under these conditions and/or the variables associated with nearness to the mouth.

As noted earlier, the apparent dilution in Gravelly Run can be attributed to industrial cooling water discharges in the downstream reach. Values for Poythress Run are considerably lower than the 8.61 μg/ℓ (ppb) recorded in a nearby seep on February 25, 1976 (SWCB, 18, 1976). However, flows here are totally dependent upon recent weather events and therefore fluctuations in Kepone content may not reflect decreases in Kepone residuals as much as differences in precipitation patterns.

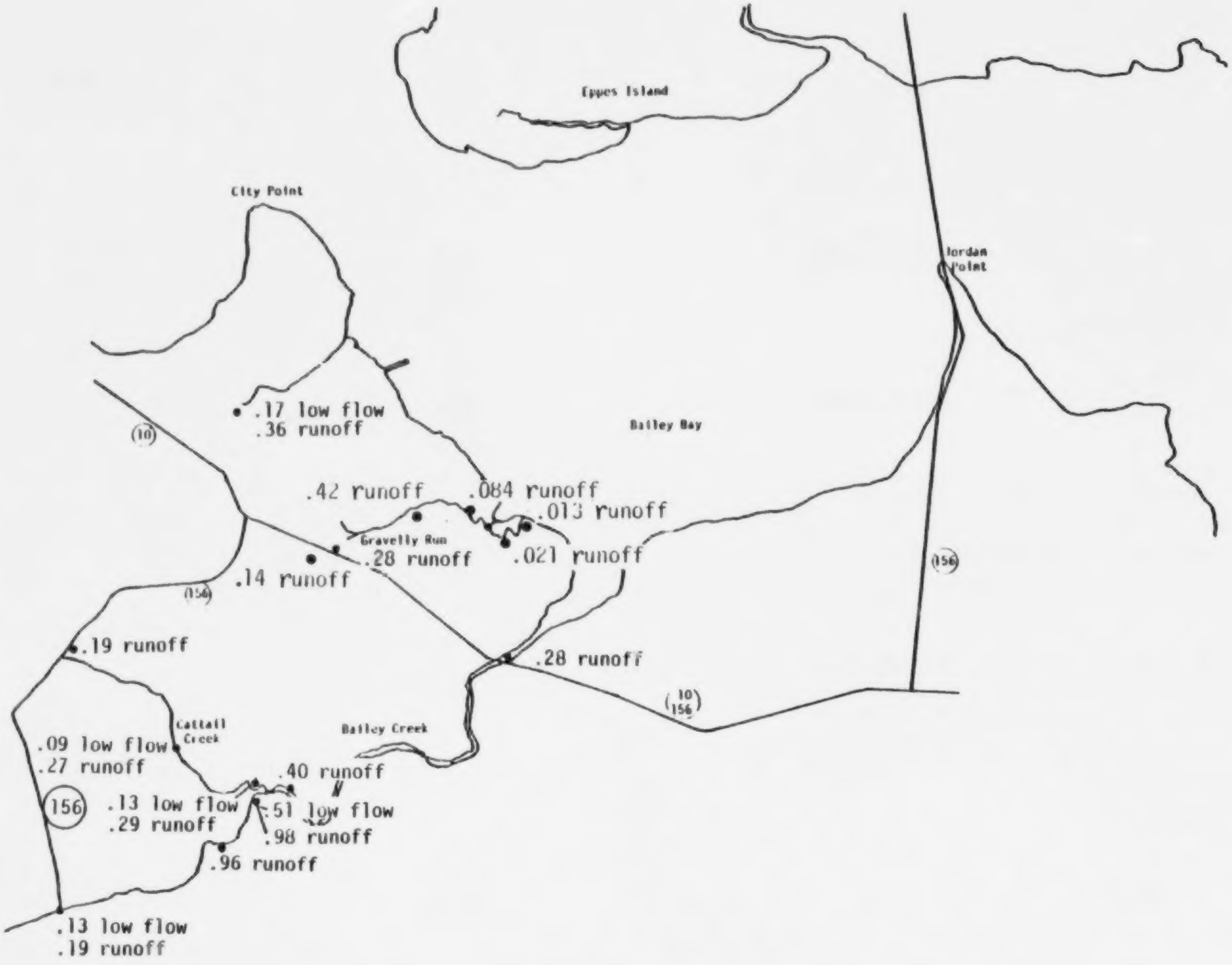
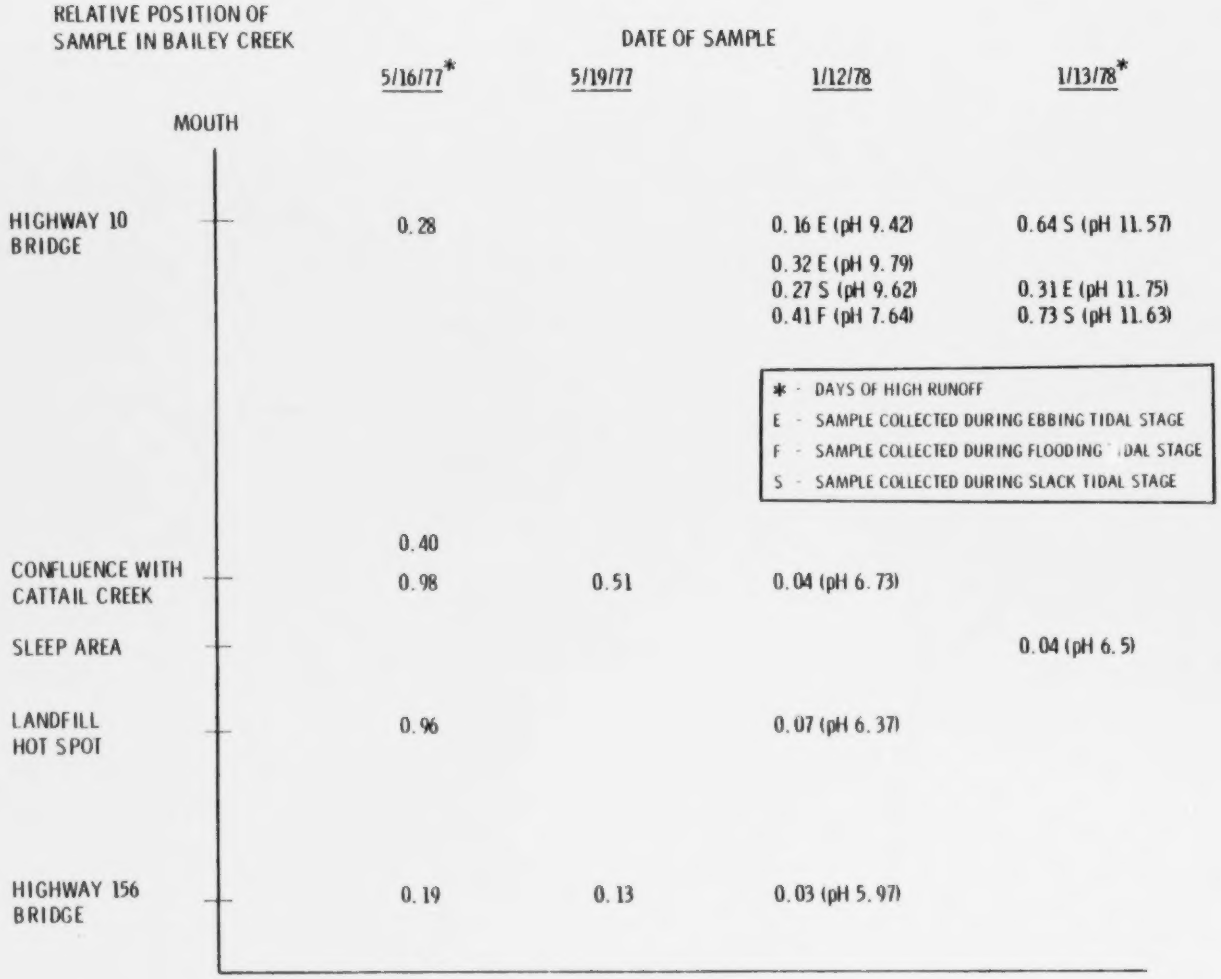

Eppes Island
City Point
Jordan Point
Bailey Bay
(10)
(156)
.17 low flow
.36 runoff
.42 runoff
.084 runoff
.013 runoff
Gravelly Run
.28 runoff
.021 runoff
.14 runoff
(156)
.19 runoff
.28 runoff
10
156
Cattail Creek
Bailey Creek
.09 low flow
.27 runoff
.40 runoff
156
.13 low flow
.29 runoff
.51 low flow
.98 runoff
.96 runoff
.13 low flow
.19 runoff

FIGURE V.15. Effect of Runoff on Movement of Kepone in Hopewell Area Concentrations in μg/ℓ (ppb)



RELATIVE POSITION OF SAMPLE IN BAILEY CREEK	DATE OF SAMPLE 5/16/77*	5/19/77	1/12/78	1/13/78*
HIGHWAY 10 BRIDGE	0.28		0.16 E (pH 9.42) 0.32 E (pH 9.79) 0.27 S (pH 9.62) 0.41 F (pH 7.64)	0.64 S (pH 11.57) 0.31 E (pH 11.75) 0.73 S (pH 11.63)
CONFLUENCE WITH CATTAIL CREEK	0.40 0.98	0.51	0.04 (pH 6.73)	
SLEEP AREA				0.04 (pH 6.5)
LANDFILL HOT SPOT	0.96		0.07 (pH 6.37)	
HIGHWAY 156 BRIDGE	0.19	0.13	0.03 (pH 5.97)	

* - DAYS OF HIGH RUNOFF
E - SAMPLE COLLECTED DURING EBBING TIDAL STAGE
F - SAMPLE COLLECTED DURING FLOODING TIDAL STAGE
S - SAMPLE COLLECTED DURING SLACK TIDAL STAGE

FIGURE V.16. Relation of Bailey Creek Kepone Concentrations to Position and Conditions (μg/ℓ-ppb)

An approximation of the total quantity of Kepone transported from streams during low flow and runoff conditions was made using these data and data for streamflow at the point of sampling. The results are presented in Table V.16. They indicate that, based on the assumptions previously stated during high flow periods there is approximately 20 times the Kepone discharged per day as there is during dry weather flow. An observation which must temper this conclusion is that there are many seeps and nonpoint sources which could add to the total Kepone burden in the Bay. It is also important that these tributaries are tidally influenced so some Kepone may be cycled back to the Creek with incoming tides.

On September 7, 1977 a set of overland runoff samples was taken from around Hopewell. Sample locations and results of Kepone analyses are presented in Figure V.17. In general, Kepone concentrations in runoff are high near the Life Science Products plant site and decline outward. The high values at that plant site (252 μg/ℓ-ppm) are similar to the values reported on May 4, 1977 (387-394 μg/ℓ-ppb). The two values near the head of Cattail Creek (1.14 and 0.26 μg/ℓ-ppb Kepone) were taken at the same location: the first at the start of the storm when runoff was rapid and turbid, the second later in the storm when runoff was clear.

Soils--

The runoff data reveal that portions of the Hopewell area still contribute Kepone to the James River via uptake from soil surfaces. Data from a sampling of surface soils from around the Hopewell area are presented in Figure V.18. Detectable levels of Kepone were found at all stations including one on Eppes Island across the James River and one across the Appomattox River. These two stations underscore the extent of airborne contamination during operation of the Kepone production facilities. The relative levels of Kepone in surface soil reflect the values reported in the previous section on overland runoff as would be anticipated.

Kepone concentrations in soil were generally found to increase at stations located nearest the site of the Life Science Products plant as might be expected. Samples taken in the vicinity of the plant itself held from 9 to 394 μg/g (ppm) Kepone. A single sample from the northwest corner of the plant site was found to contain 1535 μg/g (ppm). This area was used for storage and did not appear to have been cleaned up along with the rest of the site. At that, these levels still demonstrate a considerable reduction from the 10,000 to 20,000 μg/g (ppm) reported in 1975 at the plant, but are comparable to levels reported at a distance of 1000 m (3300 ft) (EPA, 1975). Several Nitrogen Park values are significantly higher than the 15 μg/g (ppm) reported by the State in 1976 (SWCB, 14, 1976) (Figure V.19). The difference may reflect deposition of Kepone from the plant site brought down by runoff or simply a variation in the specific sampling site. As noted earlier, the Nitrogen Park drainage is restricted so that contaminated runoff flows to a central marsh area and stands until eliminated by percolation and evaporation. A sample of standing water from the marsh was found to contain 29.32 μg/ℓ (ppb) Kepone.

TABLE V.16. APPROXIMATE KEPONE CONTRIBUTION BY TRIBUTARY DURING LOW FLOW AND RUNOFF

Tributary (Location)	Estimated Low Flow (MGD)	Low Flow - May 19		Estimated Runoff Flow (MGD)	Runoff - May 6	
		Kepone Concentration (μg/ℓ)	Total Kepone (G/Day)		Kepone Concentration (μg/ℓ)	Total Kepone (G/Day)
Bailey Creek	2.85	0.30	3.3	32	0.50	61
Gravelly Run (mouth)	0.05*	neg	neg	1	0.28	1.1
Poythress Run (headend)	Flow Diked Off†	0.17		Flow Diked Off	0.36	
Cabin Creek	0.12	0.067	neg	6	0.12	2.8
Total			3.3			64

---

* Runoff flow above allied discharge. Low flow is negligible

† Runoff flow. Outflow is negligible.

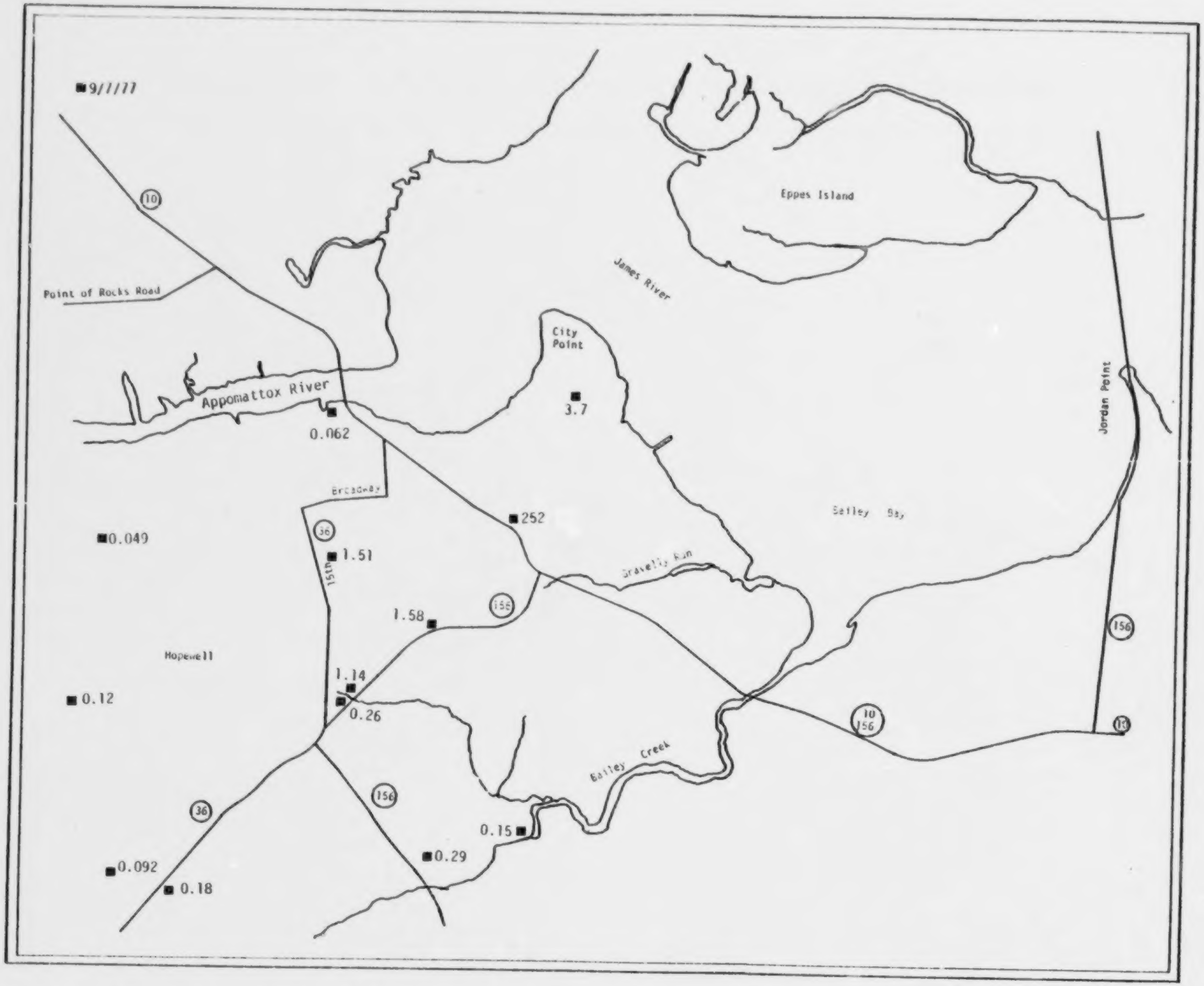

■9/7/77
10
Point of Rocks Road
Appomattox River
■0.062
Broadway
■0.049
36
■1.51
15th
Hopewell
■0.12
1.58■
156
1.14
■0.26
36
156
■0.092
■0.18
■0.29
0.15■
City Point
■3.7
■252
Gravelly Run
Bailey Creek
James River
Eppes Island
Bailey Bay
Jordan Point
156
10
156

FIGURE V.17. Runoff Sample Locations and Results of Kepone Analysis, September 7, 1977 (μg/ℓ-ppb)

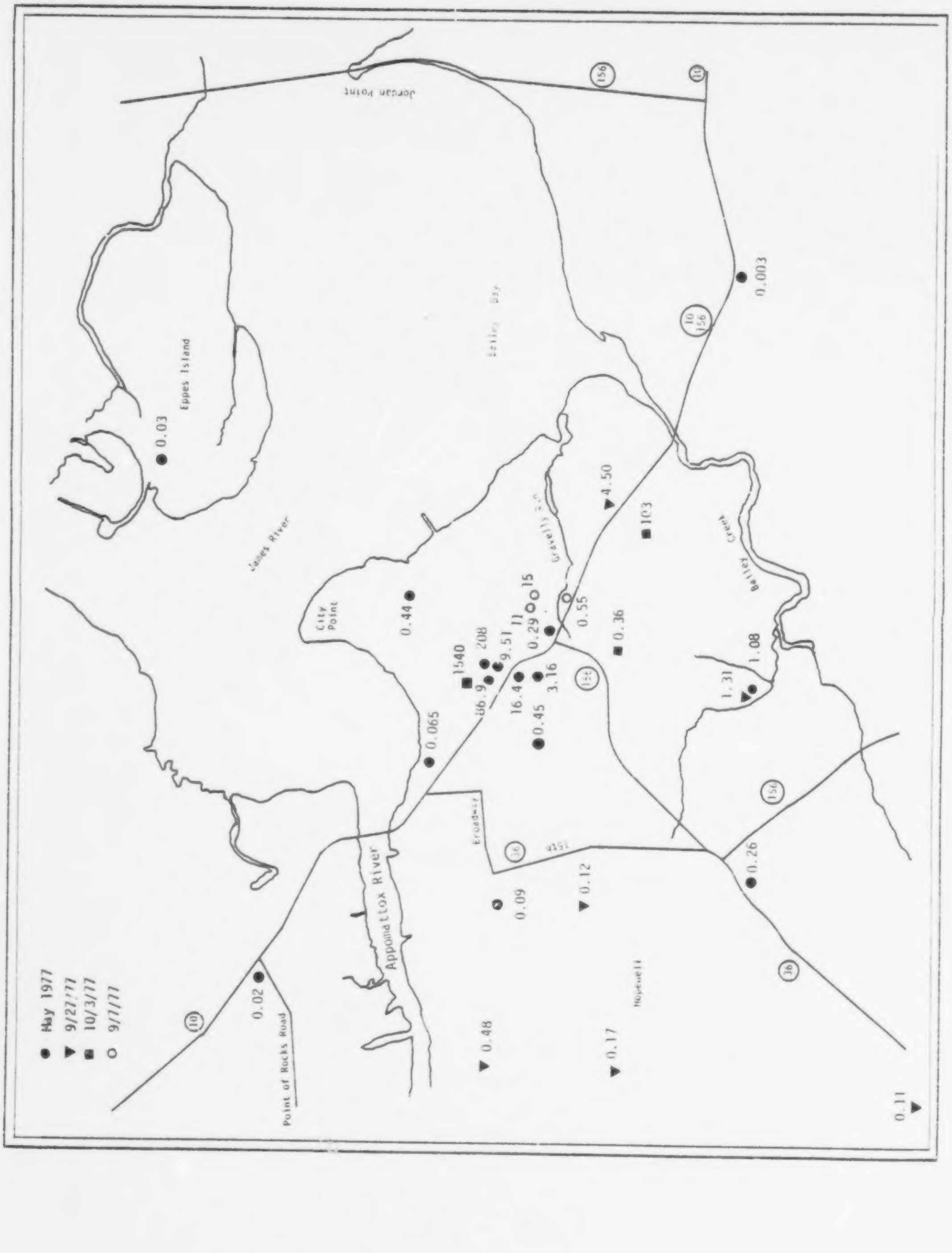

● May 1977
▼ 9/22/77
■ 10/3/77
○ 9/7/77
Point of Rocks Road
10
0.02
0.48
0.17
Hopewell
0.11
Appomattox River
0.09
0.12
36
15th
Broadway
0.26
156
0.065
0.45
16.4
86.9
1540
208
9.51
3.16
0.29
11
15
0.55
0.36
1.31
1.08
0.44
City Point
James River
Gravelly Run
4.50
103
Bailey Creek
Eppes Island
0.03
Bailey Bay
0.003
10
156
Jordan Point
156
10

FIGURE V.18. Results of Soil Analysis in Hopewell Area (μg/g-ppm)

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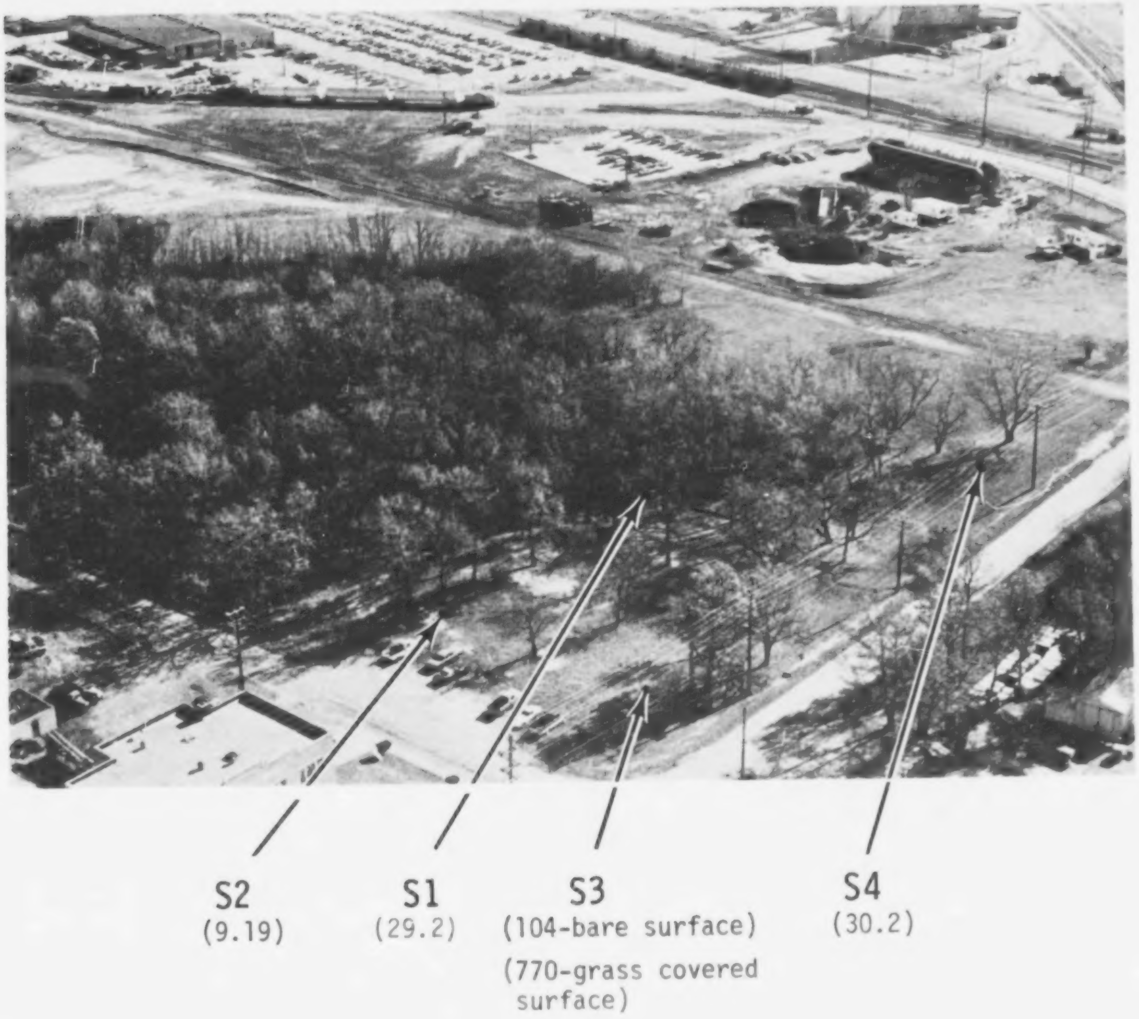

S2
(9.19)
S1
(29.2)
S3
(104-bare surface)
(770-grass covered
surface)
S4
(30.2)

FIGURE V.18. Nitrogen Park Sampling Sites (9/27/77) and Results of Subsequent Kepone Analysis (μg/g-ppm)

The top 8 cm (3 in.) of soil at this site contained 70 μg/g (ppm) Kepone. Composite samples below this segment contained 23.9 (3-6 in.), 0.19 (6-9 in.), 0.037 (9-12 in.), 0.043 (12-15 in.), and 0.14 (15-18 in.) μg/g (ppm) Kepone. This constitutes heavier contamination at depth than noted elsewhere in Hopewell soils and reflects downward transport from percolation. While cleanup action on the plant site reduced levels in the immediate area, natural forces have not significantly depleted the other areas where soil contamination occurred.

A vertical analysis at the S1 sample site in Nitrogen Park revealed Kepone concentration changes with depth as follows:

Depth (in.)	Kepone Concentration μg/g (ppm)
1	29.2
2	0.76
3	0.35
4	0.31
5	0.097
6	0.060
7	0.038
8	0.091
9	0.23
10	0.80

In general, the residual levels reveal that downward movement has occurred, but that attenuation in soil is also important. No explanation has been found for the apparent increase in Kepone at the 8 to 10 in. level. The results from site S3 reinforce observations that plant cover retains Kepone. Hence, revegetation of bare areas may in fact decrease subsequent contaminated runoff by providing a mechanism for retaining Kepone.

Several other sites were sampled at depth to ascertain if percolation of Kepone is widespread. Results are presented in Table V.17. These samples are similar to those from Nitrogen Park in that Kepone concentrations drop an order of magnitude between the first and second inch of surface soil.

Previous data reported by the Virginia State Water Control Board from cores collected while drilling the monitoring well in Nitrogen Park had indicated Kepone as low as 6.1 m (20 ft) below the surface. Consequently, hand-augered cores were collected at sites S1 and S3 to gain insight into this distribution at depth. Results are presented in Table V.18. In neither location were significant levels of Kepone found. Kepone was detectable to a depth of 3.05 m (10 ft), however. At both locations concentrations were found to increase measurably at the 1.8 to 2.5-m (6 to 8-ft) zone. This unequal distribution in the soil column may represent differences in sorption by different soil strata, or may coincide with vertical plug flow movement of Kepone from the surface.

TABLE V.17. RESULTS OF KEPONE ANALYSIS AT DEPTH IN SURFACE SOILS

Depth (in.)	Sample Site #2 Highway 10 Across From Pebbled Ammonium Nitrate	Sample Site #23 Main Pump Station	Sample Site #24 Appomattox #2 Pump Station	Sample Site #26 Western Street Pump Station
1	4.50	1.31	0.48	0.11
2	0.16	0.15	0.045	0.01
3		0.075	0.023	
4	0.077	0.049		
5		0.001		<0.007
6		<0.008		
7		0.006		
8		<0.008		
9		<0.018		<0.013
10				

TABLE V.18. VERTICAL KEPONE CONCENTRATION PATTERNS IN NITROGEN PARK

Depth (ft)	Kepone Concentration (μg/g-ppm) S1	Kepone Concentration (μg/g-ppm) S3
0	78.0	145.0
1	0.58	0.049
2	0.012	0.002
3	0.049	0.002
4	0.009	0.003
5	0.001	0.008
6	0.005	0.012
7	0.042	0.062
8	0.059	0.011
9	0.014	0.042
10	0.009	0.022

Samples taken from the field where carbon treated wastewater residue from Life Science Products closure cleanup activities was discharged were found to contain 0.36, 0.40 and 0.12 μg/g (ppm) Kepone at 2.5, 5-10, and 18-cm (1, 2-4, and 7-in.) depths, respectively. These are not out of line with other soils in the area, and therefore suggest that no significant contamination resulted from the discharge activity.

An extensive soil sampling was also conducted in the area around the Life Science Products plant site. This sampling was similar to the runoff sampling presented in Figure V.14. Sample site locations and results are presented in Figure V.20. The highest concentrations of Kepone in surface soils were found in the adjacent lots occupied by the Cavalier Ice plant (447 μg/g-ppm) and a lot just North of the former site (122 and 938 μg/g-ppm). The pattern of Kepone levels in soil continues the patterns noted previously for runoff (Figure V.14). In general Kepone concentrations in runoff exceed 5 μg/ℓ (ppb) where surface soil concentrations exceed 5 μg/g (ppm) Kepone.

In order to determine current Kepone loading in surface soils, an estimate was made based on:

Acres	Contamination Level (μg/g-ppm Kepone)
10,000	0.1
1,000	1.0
1	100
0.1	1000

Only the top inch of soil was considered since vertical profile analysis has revealed a drop of one or more orders of magnitude in Kepone concentrations between surface soils and soils 1 in. below the surface. As a result, it is estimated that Kepone residues do not exceed 45 to 450 kg (100 to 1000 lb) in surface soils of the 11,000-acre area encompassing Hopewell. This is somewhat overstated because of the use of high acreage values for each concentration and the presence of paved and covered areas in Hopewell where Kepone deposits have been swept away or otherwise dislodged.

Additional pockets of Kepone in the soil were not accounted for in this sampling plan. In particular, it is known that disposal of Kepone residuals took place at the Pebbled Ammonium Nitrate and the municipal landfill the Life Science Products production period. These are discussed separately in subsequent sections.

Ground water--

Given the widespread distribution of Kepone in soil and its apparent mobility during runoff conditions, ground-water contamination would be expected in areas where percolation occurs. Historical data from monitoring wells confirm contamination in several areas. However, apparent trends in Kepone contamination and the determination that several of the key wells have never produced water prompted conduct of an independent analysis of well water in May 1977. Results of that effort are given in Figure V.21.

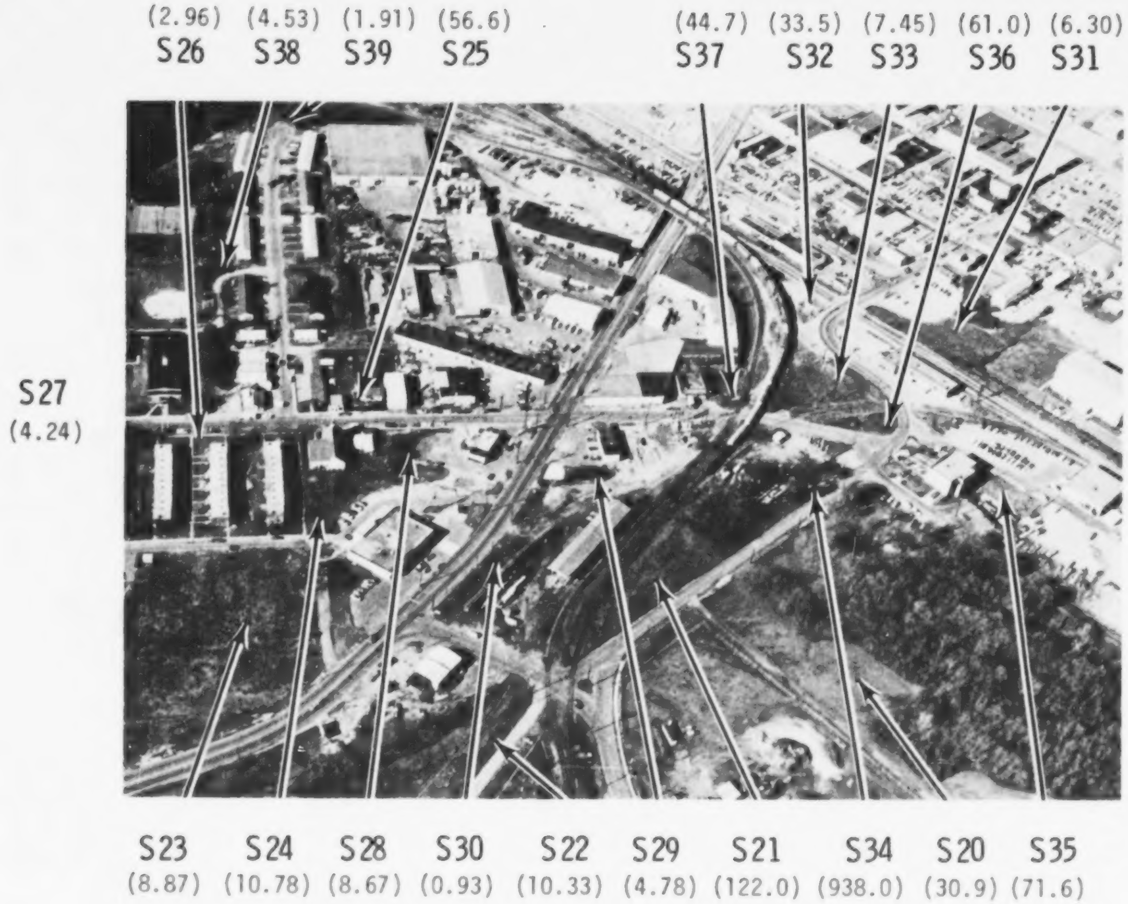

(2.96) S26
(4.53) S38
(1.91) S39
(56.6) S25
(44.7) S37
(33.5) S32
(7.45) S33
(61.0) S36
(6.30) S31
S27 (4.24)
S23 (8.87)
S24 (10.78)
S28 (8.67)
S30 (0.93)
S22 (10.33)
S29 (4.78)
S21 (122.0)
S34 (938.0)
S20 (30.9)
S35 (71.6)

FIGURE V.20. Soil Sampling Locations and Kepone Concentrations in Open Areas Around the Life Science Site (2/4/78) (μg/g-ppm)

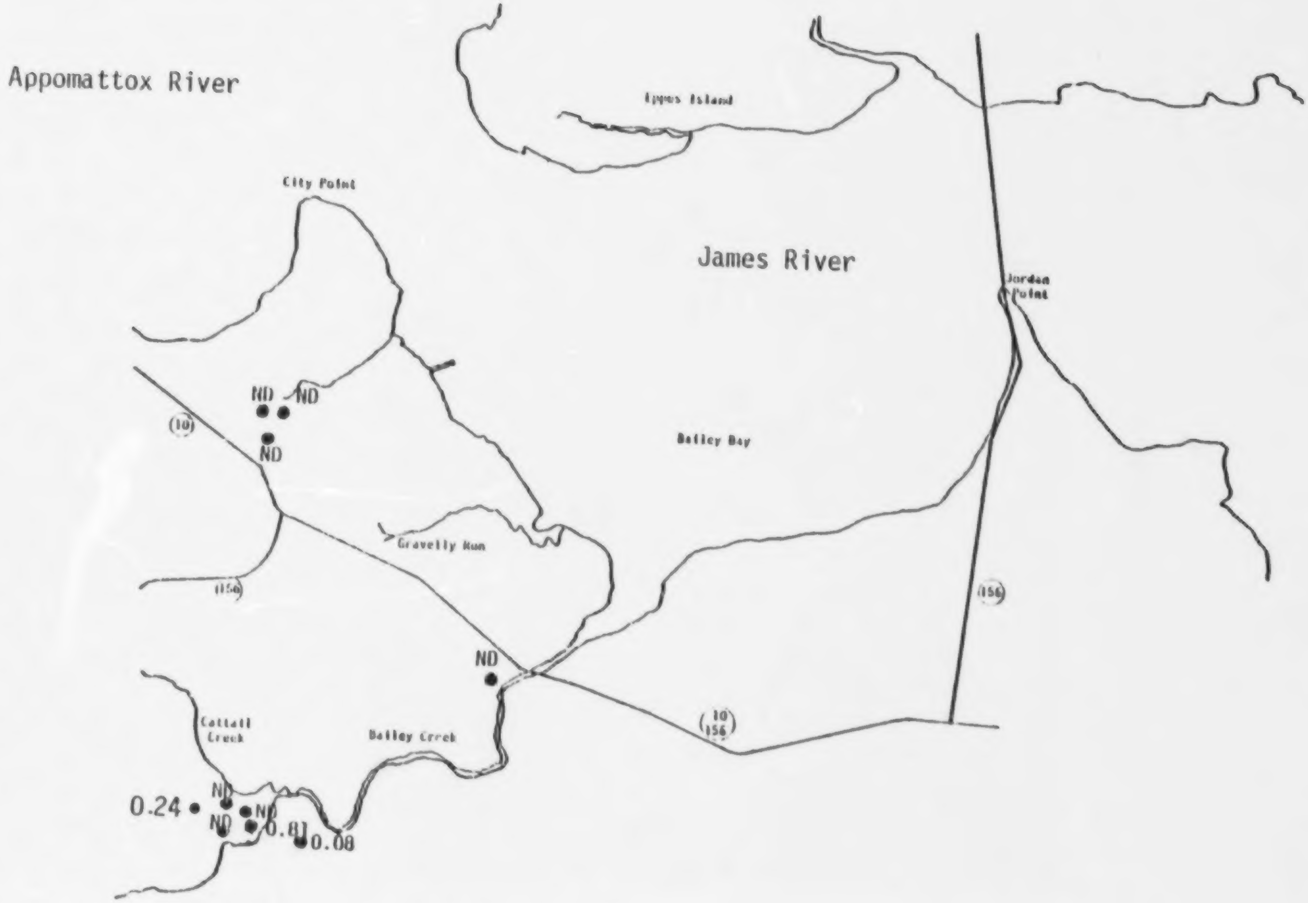

Appomattox River
Eppes Island
City Point
James River
Jordan Point
Bailey Bay
ND
ND
ND
(10)
Gravelly Run
(156)
ND
(156)
(10/156)
Cattail Creek
Bailey Creek
0.24
ND
ND
ND
0.81
0.08

FIGURE V.21. Results of Ground-water Analysis, May 17-18, 1977 (μg/ℓ-ppb)

Detectable levels of Kepone were restricted to three wells: a monitoring well at the landfill, one of the monitoring wells at the disposal lagoon, and the J. W. Quick private well. Historical trends for these and other monitoring wells can be found in Table III.3.

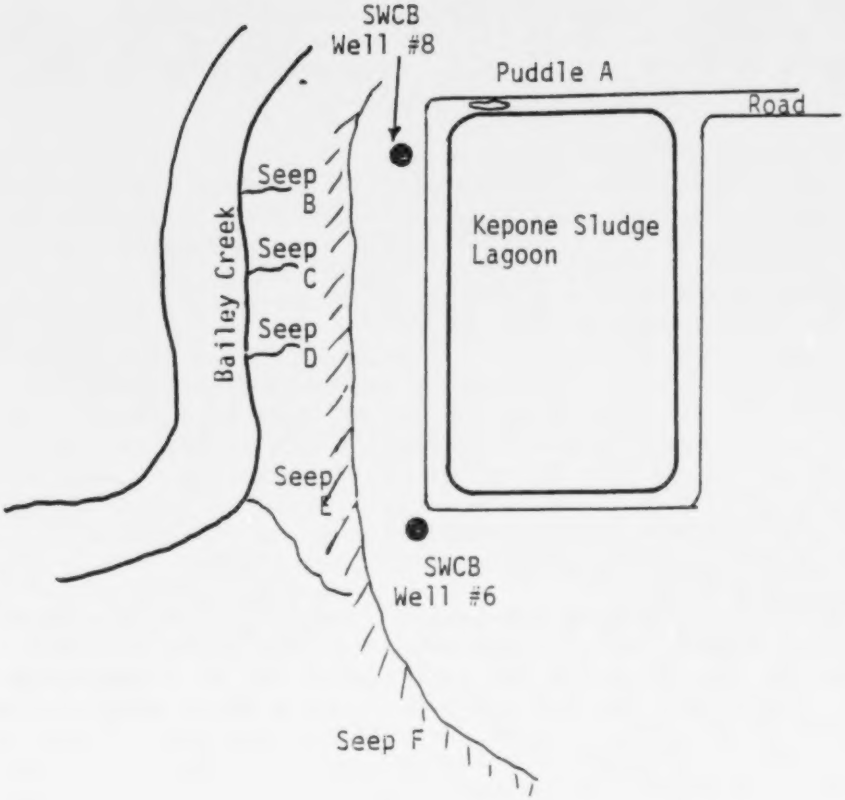
The Kepone Sludge Lagoon--

As noted earlier, a 5,700 m^3 (1.5 million gal) lagoon was constructed to hold contaminated sludge from the sewage treatment plant digesters. The potential that this lagoon could contribute Kepone-contaminated leachate to Bailey Creek led to a series of investigations throughout the spring of 1977. Initially attention was paid to the monitoring of seeps discovered in the area. Locations of these are illustrated in Figure V.22. Results of Kepone analysis are presented in Table V.19. All seeps had detectable levels of Kepone; B and E exceeded levels measured in the monitoring well on the south corner of the lagoon. They are also much higher than the 0.05 μg/ℓ (ppb) detected in the same seeps by State officials in 1976 (SWCB, 18, 1976). Centrifuging did not reduce the Kepone levels and hence they appear to result from the dissolved form rather than particulate Kepone or Kepone sorbed onto particles. Desorption tests with contaminated soil in the area of the seep produced no more than 0.72 μg/ℓ (ppb) after 90 days contact.

A third set of water samples was taken on August 15 from the lagoon itself, the marsh seep E, seep C, monitoring well No. 5 in the landfill just upgradient from the lagoon and the monitoring well (No. 8) at the south end of the lagoon. These were then subjected to a series of chemical analyses to determine if further evidence could be surfaced linking water in the lagoon to that discharged by the seeps. Results are given in Table V.20. Samples were also taken in September for further Kepone analysis. These revealed much higher levels of contamination including 77.3 μg/ℓ (ppb) Kepone in a new seep (F) discovered at the base of the embankment below the lagoon and a value of 361 μg/ℓ (ppb) Kepone from the source of seep E. Historical values for the Kepone concentration in the lagoon and various seeps are summarized in Table V.20.

From the parameters measured, it is concluded that a link exists between the two water sources: the lagoon and seep E. In addition to the previously discussed correlation in Kepone values, there are significantly higher concentrations of phosphate, chloride, fluoride, conductivity, antimony, hardness, pH, and alkalinity in these two samples than in any of the others. Indeed, of the parameters tested, only sulfate and nitrate do not correspond. All parameters would not be expected to reflect the same dilution ratios since varying levels of interaction with the soil will occur. Hence, phosphate, which often precipitates out in soil, may appear to be more effectively diluted than chloride which is quite mobile.

From the above it is probable that Kepone is leaking from the lagoon. Kepone concentrations in seeps are markedly higher than reported in 1976, and those for E exceed all levels in the creek, sewage treatment plant outfall, and other potential sources of Kepone except the lagoon. However, it should be noted that clandestine dumping in the area could have occurred, thus feeding leachate without input from the lagoon.



A - Mud Puddle in road - apparent seepage into this puddle.
B - Seep into creek out of hill side, <0.1 cfs.
C - Small seep, wet ground, no noticeable above ground flow.
D - Seep into creek from hillside, 0.1-0.2 cfs.
E - Seep or flow from marsh, upstream from sewage outflow but could be influenced by it.

FIGURE V.22. Location of Sample Sites Around Kepone Sludge Lagoon

Soil data also indicate potential leakage. The north lagoon well, monitoring well No. 6, was dug in February 1976 or 7 months after construction of the lagoon. At that time soil analyses revealed a surface Kepone level of 0.18 μg/g (ppm) and a level of 0.26 μg/g (ppm) Kepone at 3.3 m (10 ft). Other than the well at Nitrogen Park (No. 10), this was the only well where Kepone was found that deep; at Nitrogen Park, Kepone concentrations decreased with depth. Since the Kepone concentration at 3.3 m (10 ft) was greater than that at the surface, it is unlikely that the latter value represents cross contamination.

TABLE V.19. KEPONE LEVELS IN THE VICINITY OF THE SLUDGE LAGOON

Location	Kepone Concentration May 28 (μg/ℓ-ppb)	Kepone Concentration July 8 (μg/ℓ-ppb)	Centrate July 8 (μg/ℓ-ppb)	Soil July 8 (μg/g-ppm)	Sept. 6 (μg/ℓ-ppb)	September (μg/ℓ-ppb)	Nov. 11 (μg/ℓ-ppb)
A-Puddle in Road	5.28			.17, .09 - Dike high, low			
B-Seep Near Creek <0.1 cfs	0.84	0.40	0.47	.03			
C-Moist Patch at Base of Hill	0.20				.01		
D-Seep at Base, 0.1-0.2 cfs	0.22	<.12	<.17				
E-Seep in Marsh Area, .5 ℓ/sec	17.40	18.38	18.43	3.88	9.57	73.5[¶] 361[*]	
F-Seep Beneath Bank						77.3[*]	26.39
Lagoon	97.50		213			41.5[+]	

¶ - Sampled 9-15
+ - Sampled 9-16
* - Sampled 9-28

TABLE V.20. COMPARATIVE VALUES FOR COMPONENTS FOUND IN THE KEPONE SLUDGE LAGOON, SEEPS, AND NEARBY WATER

	Site	ppm SO_4	ppm PO_4 Total	ppm Cl^-	ppm F^-	ppb Kepone*	micro mhos/cm Conductivity	ppb Antimony	ppm NO_3-N	ppm Hardness	pH	ppm Alkalinity
1.	Lagoon	3.75	22.5	42	1.35	213	1,220	57	5.3	136	7.9	360
2.	Marsh Seep No. E	256	3.5	16.5	.68	18.43	1,080	77	<1	118	7.7	114
3.	Main Seep No. C	110	.76	5.0	.17	<.17	600	<16	6.4	84	6.6	40
4.	Landfill Well	<1	.57	2.0	.17		250	<16	1.8	58	7.2	88
5.	Pond Well	<1	.73	3.5	.17		240	<16	<1	52	7.2	84

---

*Data from samples of July 8.

The fluctuations in lagoon volume which are caused by intermittent inputs and outflows are further reflected by fluctuations in results from Kepone analysis over the period of 1975 to 1977. These are summarized for both supernatant and solids in Table V.21. It would appear that the lagoon is not well mixed. Dilution and evaporation or varying levels of solids in supernatant samples as well as changing chemical parameters have caused periodic fluctuations in Kepone concentrations.

TABLE V.21. RESULTS OF PERIODIC KEPONE ANALYSIS IN DISPOSAL LAGOON

Date (organization)(*)	Supernatant (μg/ℓ-ppb) NW End	Supernatant (μg/ℓ-ppb) SE End	Solids (μg/g-ppm) NW End	Solids (μg/g-ppm) SE End
1975				
December 4 (SWCB)		1450	1	550
1977				
April 28 (PNL)	97.5			
May 11 (PNL)	27.7		828	95.9
July 8 (PNL)	213			

(*) SWCB - Virginia State Water Control Board.
PNL - Pacific Northwest Laboratory (Battelle).

Pebbled Ammonium Nitrate Plant Site--

Little has been reported about the disposal of Kepone and related wastes at the Pebbled Ammonium Nitrate (PAN) plant site. Knowledge that disposal was performed there and the discovery of a 5-ft composite soil sample containing 27,000 μg/g (ppm) Kepone focused attention on this location as a priority for field sampling and evaluation. At the same time, an effort was made to document the history of disposal operations at the site in order to develop details for the sampling plan and gain insight for subsequent data evaluation. The information gained from these efforts is summarized in the following sections along with results of analysis on environmental samples.

Background--In the latter part of 1974, pressure was exerted on Life Science Products Company to reduce the amount of Kepone discharged from its facilities into the city sewer system. The State Water Control Board had discovered that Kepone was interfering with the digesters at the sewage treatment plant (Senate Hearings, 1976). As a result, Life Science Products began to look for an alternative means for disposing of its contaminated wastewater. In December of 1974, discharge of wastewater began at the site of the Pebbled Ammonia Nitrate (PAN) plant.

Site Description--The PAN site lies along the southern edge of the State Highway 10, approximately one-half mile west of Bailey Creek as depicted in Figures V.23 and V.24. It is in the outskirts of the city of Hopewell, relatively isolated in an industrial area of town. In 1970, Allied Chemical Corporation sold the deserted plant and site which was subsequently used by Greenbank Services, Inc. for salvage, storage, office space, and sand quarrying.

Kepone Disposal at the Site--In late 1974, Mr. Virgil Hundtofte, Plant Manager of Life Science Products Company, approached Greenbank Services, regarding use of the PAN site for disposal of Life Science Products plant wastewater. With assurance from Mr. Hundtofte that the wastewater was harmless, permission was granted and a trench dug to accept the waste.

The 6.1-m (20-ft) wide trench into which the wastewater was discharged measured roughly 1.2 m (4 ft) deep by 11 m (35 ft) long. It lay above a steep ravine where drainage flows outward through a culvert under Highway 10 into a flat marsh. Water flows in a northerly direction through the marsh for approximately one quarter mile, then turns east and joins Bailey Creek below the Highway 10 bridge.

There are no good estimates currently for either the amount of Life Science Products wastewater discharged into the trench or the water's concentration of Kepone. It is known that the trench received wastewater on a regular basis, perhaps daily, from December 1974 into the summer of 1975. Life Science Products employees would truck the material to the PAN site in a pick-up mounted 250-gal tank and discharge it into the trench generally at night. Documentation of one such incident occurred when a Hopewell policeman sighted this action taking place in the early morning hours, questioned the men involved, and filed a report. Testimony on file at the Virginia Attorney General's office indicates incidents may have numbered in the hundreds.

Field Sample Analysis--On October 3, 1977, samples were collected at the PAN site as part of a general sampling program of the Hopewell area. Two surface samples were taken of the top inch of soil: one directly over the filled-in disposal trench, and the second immediately below a small earthen dam in the ravine. A subsurface sample was also taken 25 cm (10 in.) below the sample from the trench area. In addition, a sample of seepage water from the ravine was collected from the culvert under Highway 10. The level of Kepone detected in these samples is presented in Table V.22.

A subsequent screening of the PAN site was conducted on November 22, 1977. Sample sites and results are presented in Figure V.25. From these data it is apparent that Kepone-contaminated soil persists in the area of the trench (T series). Apparent horizontal movement in the surface soil has occurred in the natural drainage direction with surface samples downstream reaching 84.3 μg/g (ppm) Kepone. Samples taken on the west face of the quarry pit (Figure V.24) reveal very low Kepone levels with no real variation with depth:

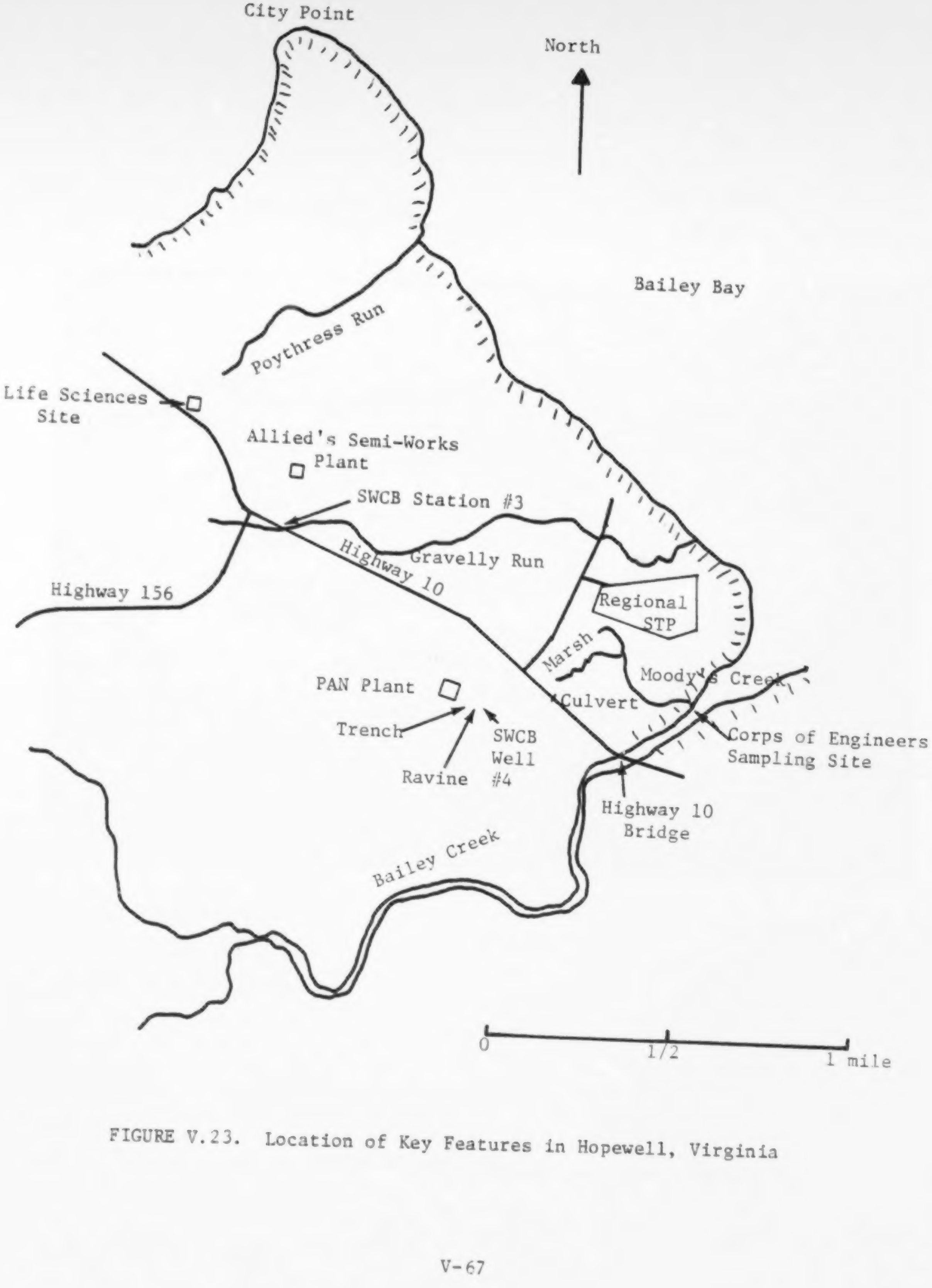

City Point
North
Bailey Bay
Poythress Run
Life Sciences Site
Allied's Semi-Works Plant
SWCB Station #3
Highway 10
Gravelly Run
Highway 156
Regional STP
Marsh
Moody's Creek
PAN Plant
Culvert
Trench
SWCB Well #4
Ravine
Corps of Engineers Sampling Site
Highway 10 Bridge
Bailey Creek
0
1/2
1 mile

FIGURE V.23. Location of Key Features in Hopewell, Virginia

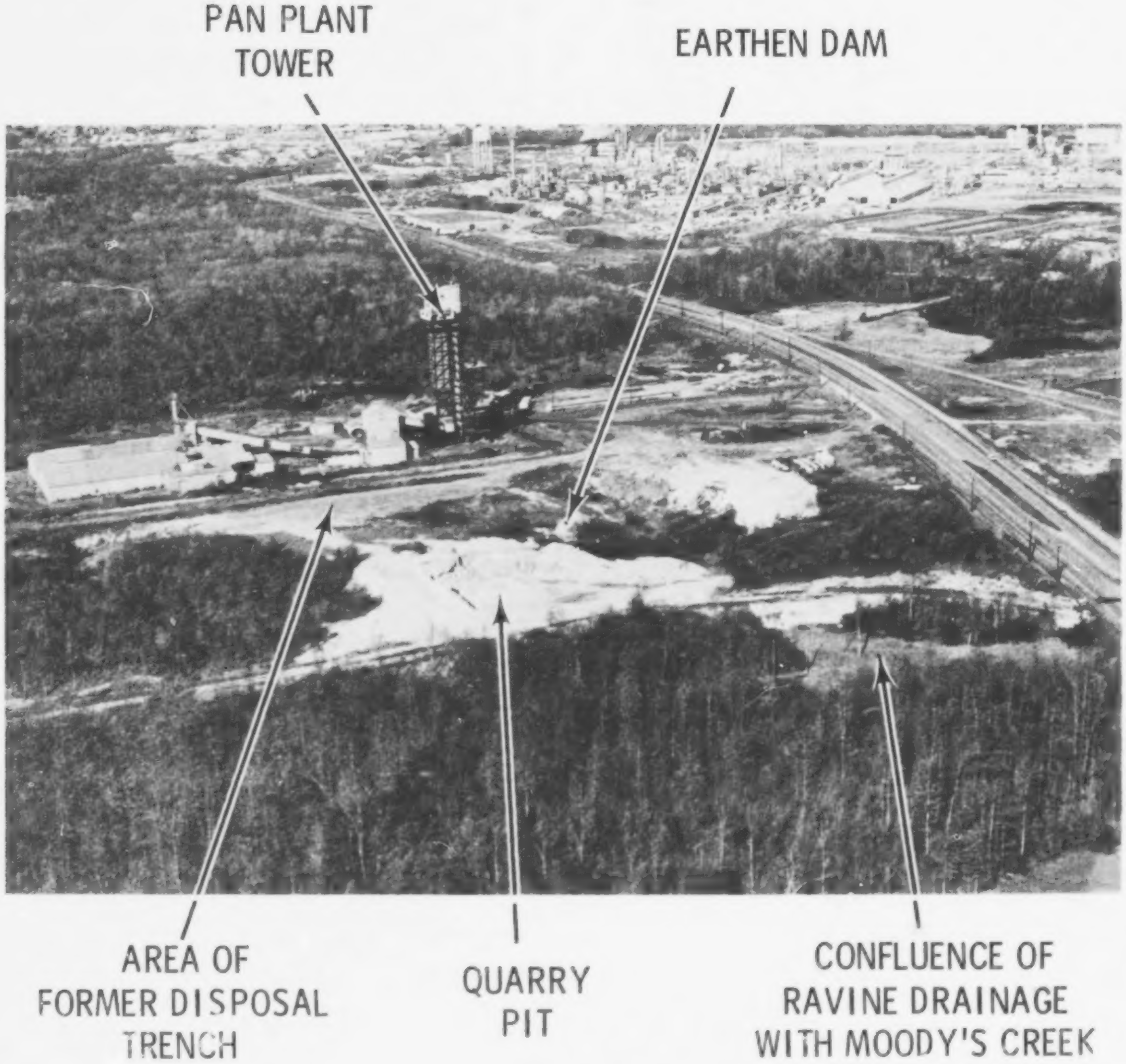

PAN PLANT TOWER
EARTHEN DAM
AREA OF FORMER DISPOSAL TRENCH
QUARRY PIT
CONFLUENCE OF RAVINE DRAINAGE WITH MOODY'S CREEK

FIGURE V.24. The Pebbled Ammonium Nitrate Plant Site

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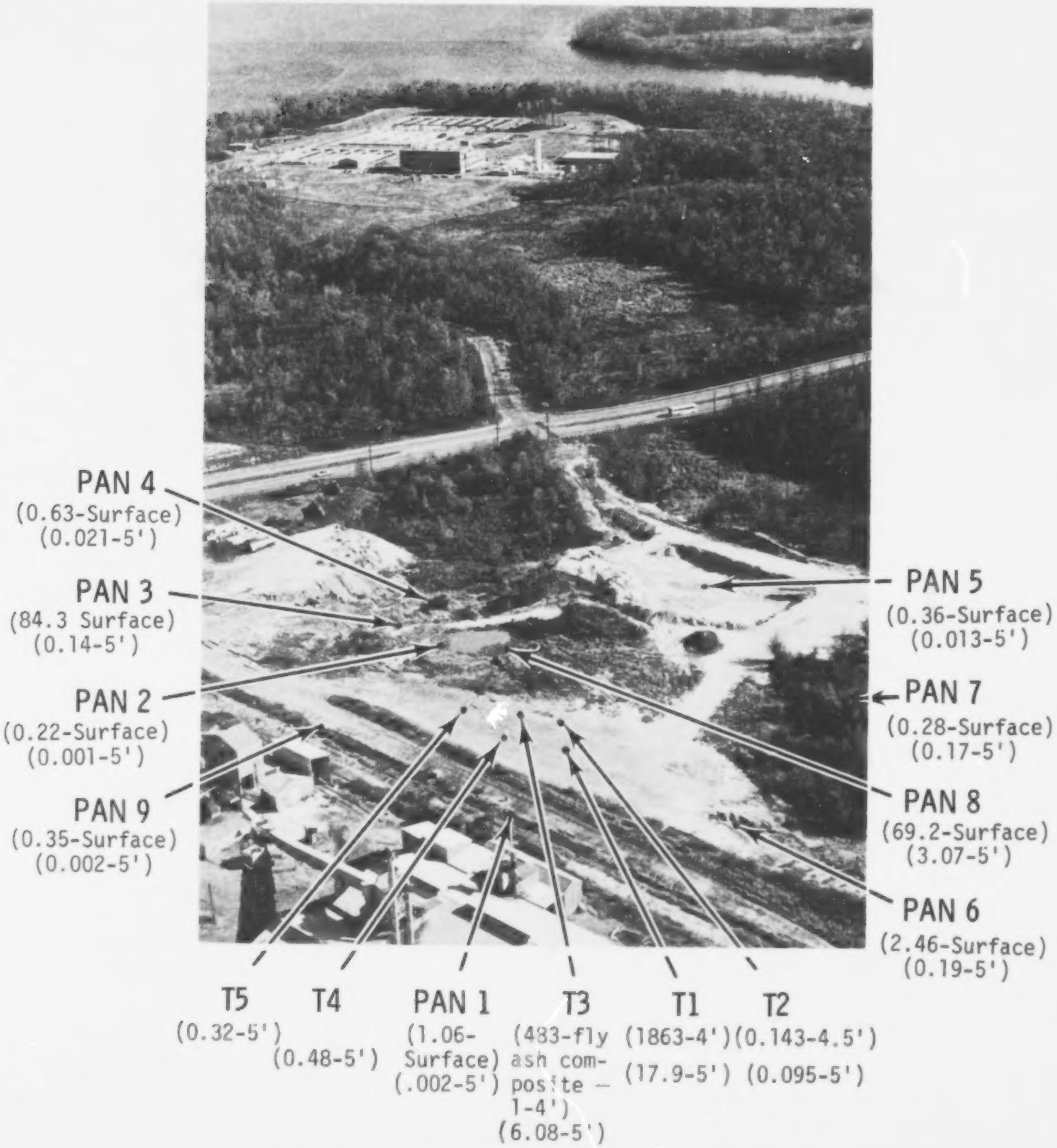

PAN 4
(0.63-Surface)
(0.021-5')
PAN 3
(84.3 Surface)
(0.14-5')
PAN 2
(0.22-Surface)
(0.001-5')
PAN 9
(0.35-Surface)
(0.002-5')
PAN 5
(0.36-Surface)
(0.013-5')
PAN 7
(0.28-Surface)
(0.17-5')
PAN 8
(69.2-Surface)
(3.07-5')
PAN 6
(2.46-Surface)
(0.19-5')
T5
(0.32-5')
T4
(0.48-5')
PAN 1
(1.06-Surface)
(.002-5')
T3
(483-fly ash composite – 1-4')
(6.08-5')
T1
(1863-4')
(17.9-5')
T2
(0.143-4.5')
(0.095-5')

FIGURE V.25. Auger Sampling Locations and Results November 23, 1977 (µg/g-ppm) (Depth in feet of sample follows results.)

Depth in Feet	Kepone Concentration (μg/g-ppm)
3	0.002
8	0.002
15	0.002
18	0.007
Coarse sand layer below clay strata at 18 ft	0.007

TABLE V.22. KEPONE CONCENTRATION AT PAN SITE

Sample	Kepone Concentration
Surface soil on top of disposal trench	104.4 ppm
Subsurface soil (10 in.) from disposal trench	0.16 ppm
Surface soil below earthen dam	2.99 ppm
Water from culvert	1.55 ppb

After review of data, auger samples were supplemented with deep core drilling and hand core sampling. Locations of these samples and subsequent results are presented in Figures V.26 and V.27. Augured samples illustrated in Figure V.26 were analyzed as composites at depth intervals. Results are given in Table V.23. A variability of nearly three orders of magnitude was found at the sites, but all levels were low in Kepone content. Extrapolation of the values found account for no more than 100 kg (220 lb) of Kepone.

Strata from cores A, B, G, and H (Figure V.26) were also analyzed for hexachlorocyclopentadiene. Results are given in Table V.24. Hexachlorocyclopentadiene (HCP) residuals are roughly comparable to those for Kepone except for the area of core A where up to 192 μg/g (ppm) HCP were found at 5.8 to 6.1 m (19 to 20 ft). This is in the disposal trench area and if it represents an area of 37 m^2 (400 ft^2) it accounts for up to 23 kg (50 lb) of HCP. Both Kepone and HCP in core A show marked concentration decreases at the water level, 8.1 m (26.6 ft), suggesting horizontal movement within the aquifer. Kepone and HCP values also increase in most cores with a substrata of sand and gravel roughly 10.4 to 10.7 m (34 to 35 ft) below the trench level. This highly pervious zone may represent the layer of maximum lateral transport.

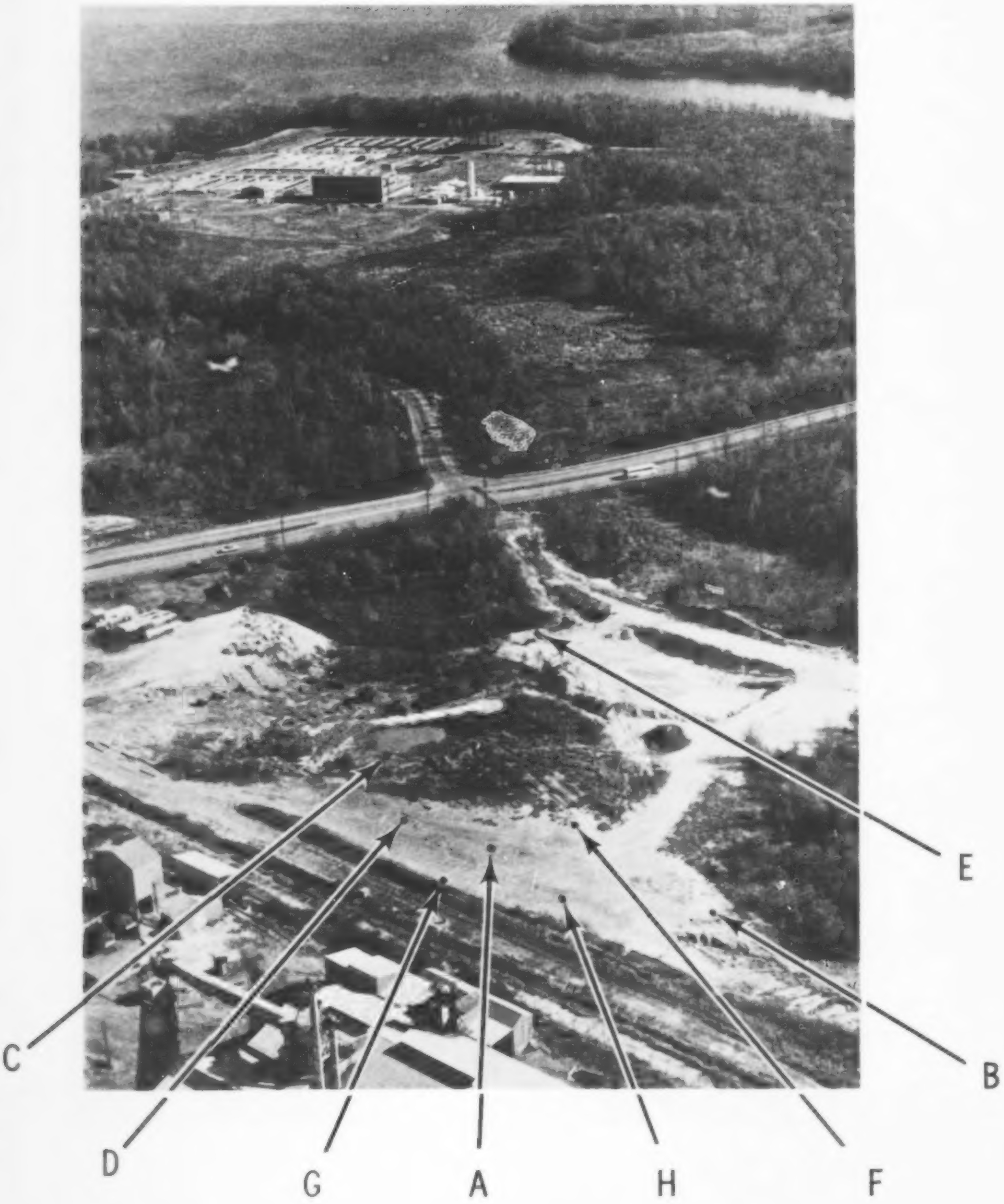


FIGURE V.26. Deep Core Drilling Locations and Results of Kepone Analysis December 5, 6, 7 & 8, 1977 (μg/g-ppm)

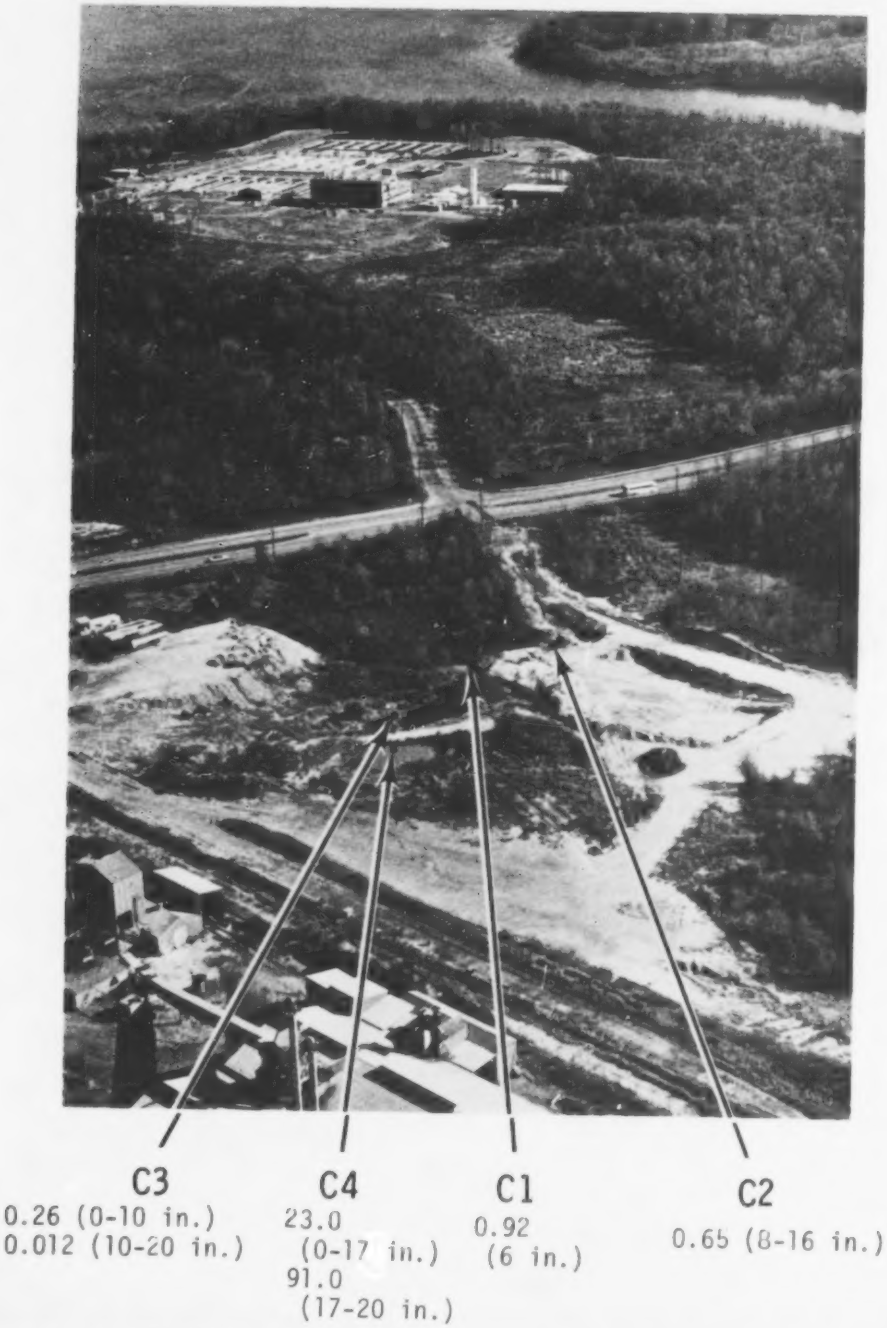

C3
0.26 (0-10 in.)
0.012 (10-20 in.)
C4
23.0
(0-17 in.)
91.0
(17-20 in.)
C1
0.92
(6 in.)
C2
0.65 (8-16 in.)

FIGURE V.27. Hand-core Sampling Locations and Results of Kepone Analysis December 7, 1977 (μg/g-ppm)

TABLE V.23. VERTICAL KEPONE PAN DISTRIBUTION IN DEEP CORES FROM THE PAN SITE (μg/g)

Composite Interval (ft)	A	B	C	D	E	F	G	H
0-1.5	0.041				0.028*			
<4-5		0.19	0.30	0.082+	0.16	0.020	6.13	0.24
6-6.5	0.74				0.023†			
9-10	0.026	0.37	0.028	0.047	0.31‡	0.002	0.026	0.058
14-15	0.018		0.018	0.005	0.015** 0.20	0.004	0.007	0.004
19-20	0.76	0.025	0.033	0.004	0.009	0.019	0.043	0.004
24-25		0.031		0.007	0.008	0.003	0.014	0.001
25-26	<0.13		0.16					
29-30	<0.17	0.15		0.025	0.007	0.005	0.13	0.002
31-32			0.015					
34-35	0.073 3.82++ 4.24oo	0.034	0.013			0.013	0.027	0.027
39-40	0.88		0.012				0.032	0.002
44-45								0.002
49-50	0.020							0.003

---

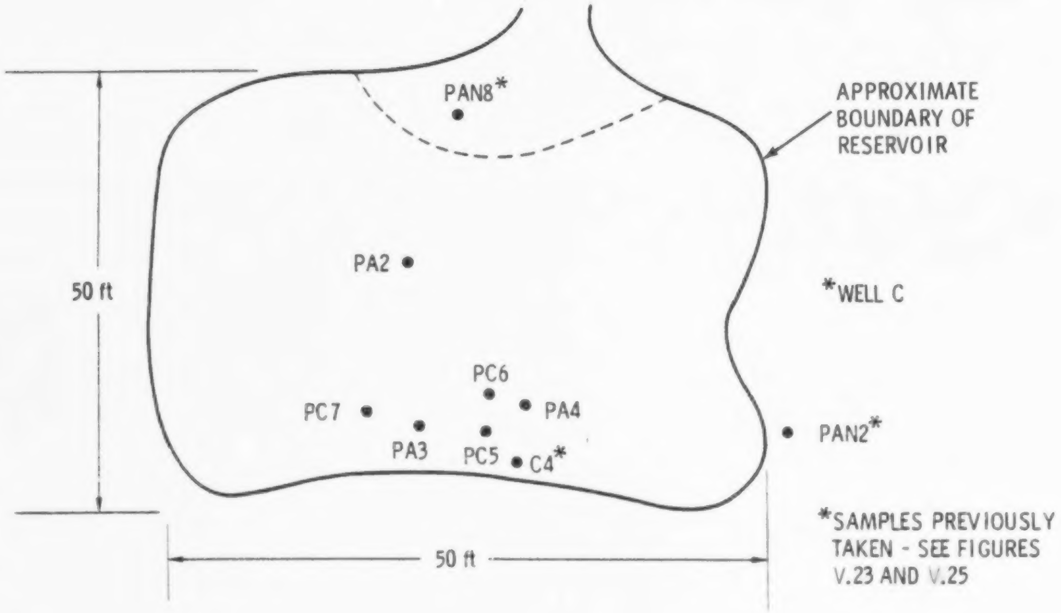
* 4-6 ft
+ 2-3 ft
† 7-8 ft
‡ 10-11 ft
** 13-14 ft
o 16-17 ft
oo 35-37 ft
++ 37-39 ft

TABLE V.24. DISTRIBUTION OF HEXACHLOROCYCLOPENTADIENE IN THE PAN SITE (μg/g-ppm)

Composite Interval (ft)	A	B	G	H
4-5		0.014	<0.028	0.096
6-6.5	0.18			
9-10		0.008		0.041
14-15			<0.004	0.014
19-20	192	<0.004	<0.004	<0.004
24-25	112	<0.004	<0.004	<0.004
29-30	0.40	<0.004	<0.004	<0.004
34-35	89	0.007	<0.004	<0.004
35-40			<0.004	
39-40	0.066			0.017
44-45	<0.015			<0.004
49-50	<0.004			<0.004

On February 1, 1978, a more extensive sampling was conducted in the area behind the earthen dam (Figure V.24) where samples PAN 3 and PAN 8 (Figure V.25) and core C4 (Figure V.27) had revealed high Kepone contamination relative to surrounding areas. Sample sites and results of core and auger analysis are presented in Figure V.28. An augered sample from the southwestern border of the site (Figure V.29) was found to contain: 0.21, 0.013, 0.41, and 0.18 ug/g (ppm) at 0.3, 1.3, 1.8, and 2.1 m (1, 4, 6, and 7 ft), respectively.

Cores were also taken in the marsh and bed of Moody's Creek which receives runoff from the PAN site. Sampling sites and results of analyses are presented in Figure V.30. Results do not indicate the presence of any major zone of Kepone in the Moody's Creek drainage.

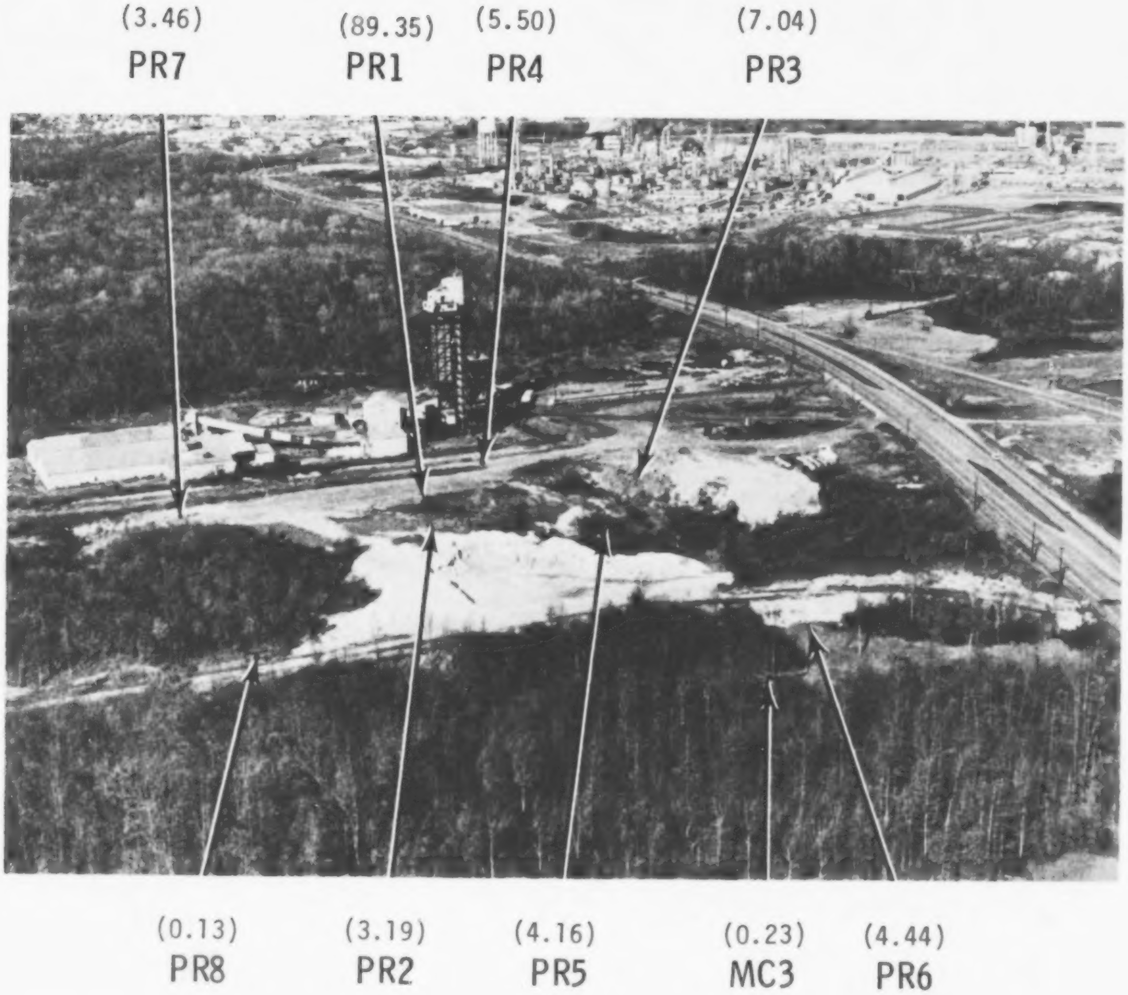

PAN8*
APPROXIMATE BOUNDARY OF RESERVOIR
PA2
50 ft
*WELL C
PC6
PC7
PA4
PA3
PC5
C4*
PAN2*
*SAMPLES PREVIOUSLY TAKEN - SEE FIGURES V.23 AND V.25
50 ft

DEPTH (FEET)	AUGER SAMPLES (µg/g-ppm) PA2	AUGER SAMPLES (µg/g-ppm) PA3†	AUGER SAMPLES (µg/g-ppm) PA4
1			74.5
2		54.7	
3		164(2.5')	39.0
4	1.9		17.2
5		81	0.36
6	1.43	0.44	0.24
6.5	0.15	0.14, 2.72	
7	0.58	0.26	1.04
8	0.36	0.20	0.13
9		0.13	0.35
10	0.43		

†AUGER HIT IMPENETRABLE OBJECT, MOVE SAMPLE 2 FEET OVER

SEGMENT	CORE SAMPLES (µg/g-ppm) PC5	CORE SAMPLES (µg/g-ppm) PC6	CORE SAMPLES (µg/g-ppm) PC7
TOP 7 IN.	44.3	63.3	37.9
MID 7 IN.	78.5	145	56.6
BOTTOM 7 IN.	116	57.3	39.7

FIGURE V.28. Kepone Residuals in the PAN Reservoir Area



(3.46)
PR7
(89.35)
PR1
(5.50)
PR4
(7.04)
PR3
(0.13)
PR8
(3.19)
PR2
(4.16)
PR5
(0.23)
MC3
(4.44)
PR6

FIGURE V.29. Kepone Concentrations in Water from the PAN Site, January 13, 1978 (μg/ℓ-ppb)

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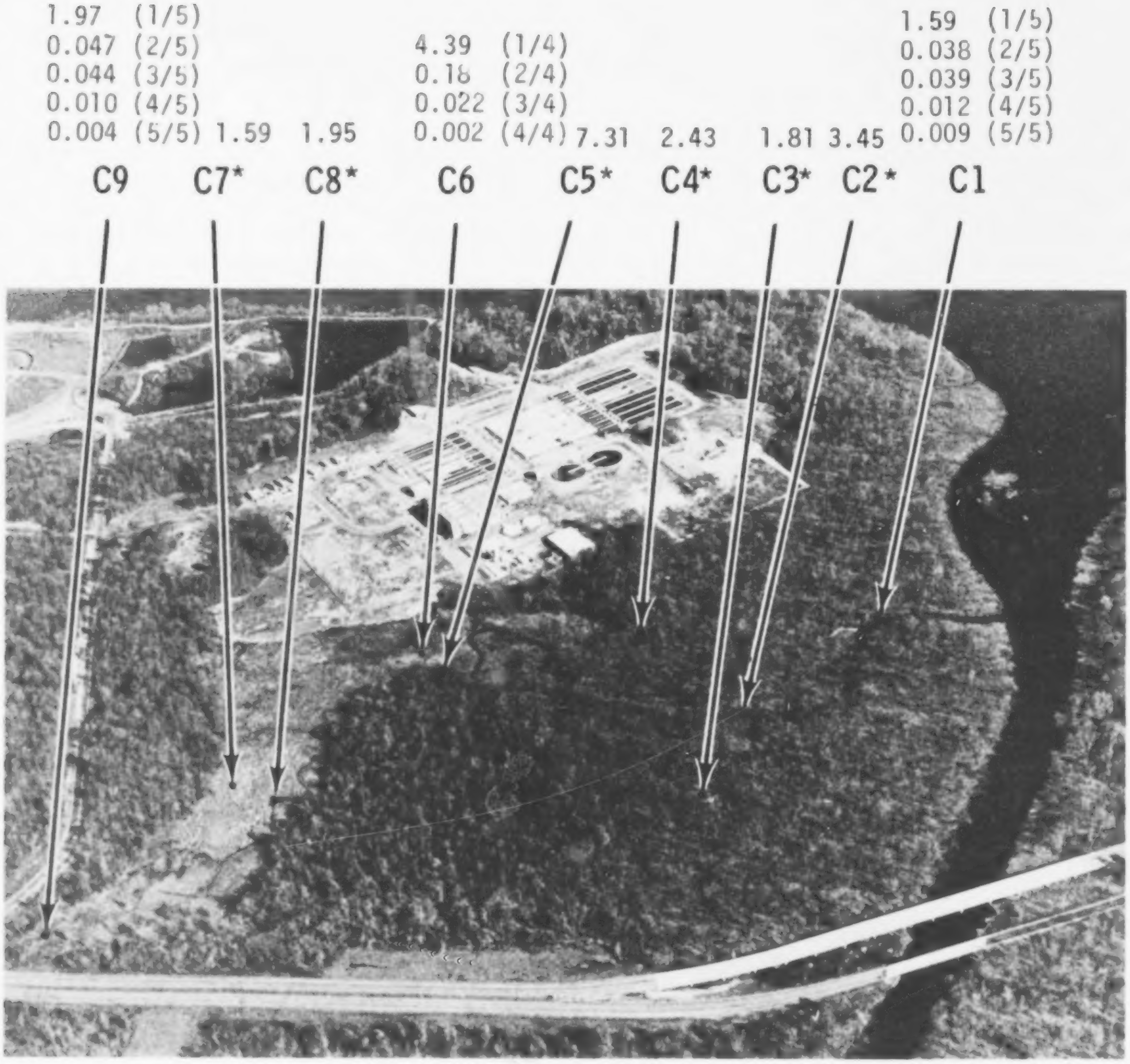

1.97 (1/5)
0.047 (2/5)
0.044 (3/5)
0.010 (4/5)
0.004 (5/5)
C9
1.59
C7*
1.95
C8*
4.39 (1/4)
0.18 (2/4)
0.022 (3/4)
0.002 (4/4)
C6
7.31
C5*
2.43
C4*
1.81
C3*
3.45
C2*
1.59 (1/5)
0.038 (2/5)
0.039 (3/5)
0.012 (4/5)
0.009 (5/5)
C1

FIGURE V.30. Results of Coring in Moody's Creek Marsh December 1, 1977 (Kepone in µg/g-ppm) Position X/5 indicates the serial 7.5 cm 3 in. segments, i.e., 1/5 = top 3 in., 3/5 = next 3 in., etc.)

---

* Data represent 15 cm (6 in.) composite from the top of the core

Water samples were collected from several locations at the PAN site during a rainstorm. Results of the sampling are shown in Figure V.29. The runoff with the highest level of Kepone (89.35 μg/ℓ) originated from the disposal trench area and flowed into the small reservoir behind the dam. All other runoff also contained elevated Kepone levels relative to general Hopewell area runoff.

Samples PR5 and PR8 represented ground-water seeps rather than overland runoff. PR5 flowed from below the dam with 4.16 μg/ℓ Kepone. PR8 had a pH of 4.3, which was the lowest pH of all the water samples collected that day and represents a particularly low value for ground water. Subsequent analyses of this seep have shown Kepone levels of 70 μg/ℓ in February 1978 and 0.25 μg/ℓ in March 1978. Ground-water seeps sampled due east of the site towards Bailey Creek contained less than 0.1 μg/ℓ Kepone and had a pH of approximately 6.5.

Runoff samples were also collected from Moody's Creek. Sample MC3, containing 0.23 μg/ℓ (ppb) Kepone, was taken directly above the Creek's confluence with the PAN ravine drainage. MC2 was collected a quarter mile downstream in the marsh, while sample MC1 was drawn from the Creek's mouth as it discharged into Bailey Creek. These samples contained levels of Kepone of 0.61 and 2.01 μg/ℓ (ppb), respectively. Water samples taken simultaneously at the adjacent reach of Bailey Creek showed Kepone concentration of approximately 0.7 μg/ℓ (ppb).

Landfill

Records and statements by former Life Science Products Company employees have revealed that Kepone-contaminated residues were also discharged at the Hopewell landfill. While some disposal locations are well known, little has been reported on their contents, and no single authority has accumulated a composite picture of where all the sites were within the landfill, when they were in use, and what they received. The information that could be gathered has been reviewed and summarized in Figure V.31.

The Life Science Products plant burial pit is the site where 2100 m^3 (2300 yd^3) of rubble from dismantling the facility were buried and marked with a permanent plaque. The miscellaneous waste disposal site was utilized during 1974 for plant wastes from Life Science Products. This included refuse and it is unknown what amounts of Kepone, if any, were deposited there. The bulk discharge area is a general zone thought to have received a bulk discharge of Kepone. Testimony on file at the State Attorney General's office indicates that in late October 1974, oil entered the quench tank at Life Science Products. Two septic tank cleaning trucks were brought in to pump out several loads apiece. These were discharged at the head of the embankment and were allowed to run down into the marsh. It is estimated that a total of 4000 lb of Kepone was released at this location. The remaining two sites were utilized by the sewage treatment plant to dispose of contaminated sewage sludge. One site was lined, and the other site was not. These received contaminated sludge prior to construction of the lagoon.

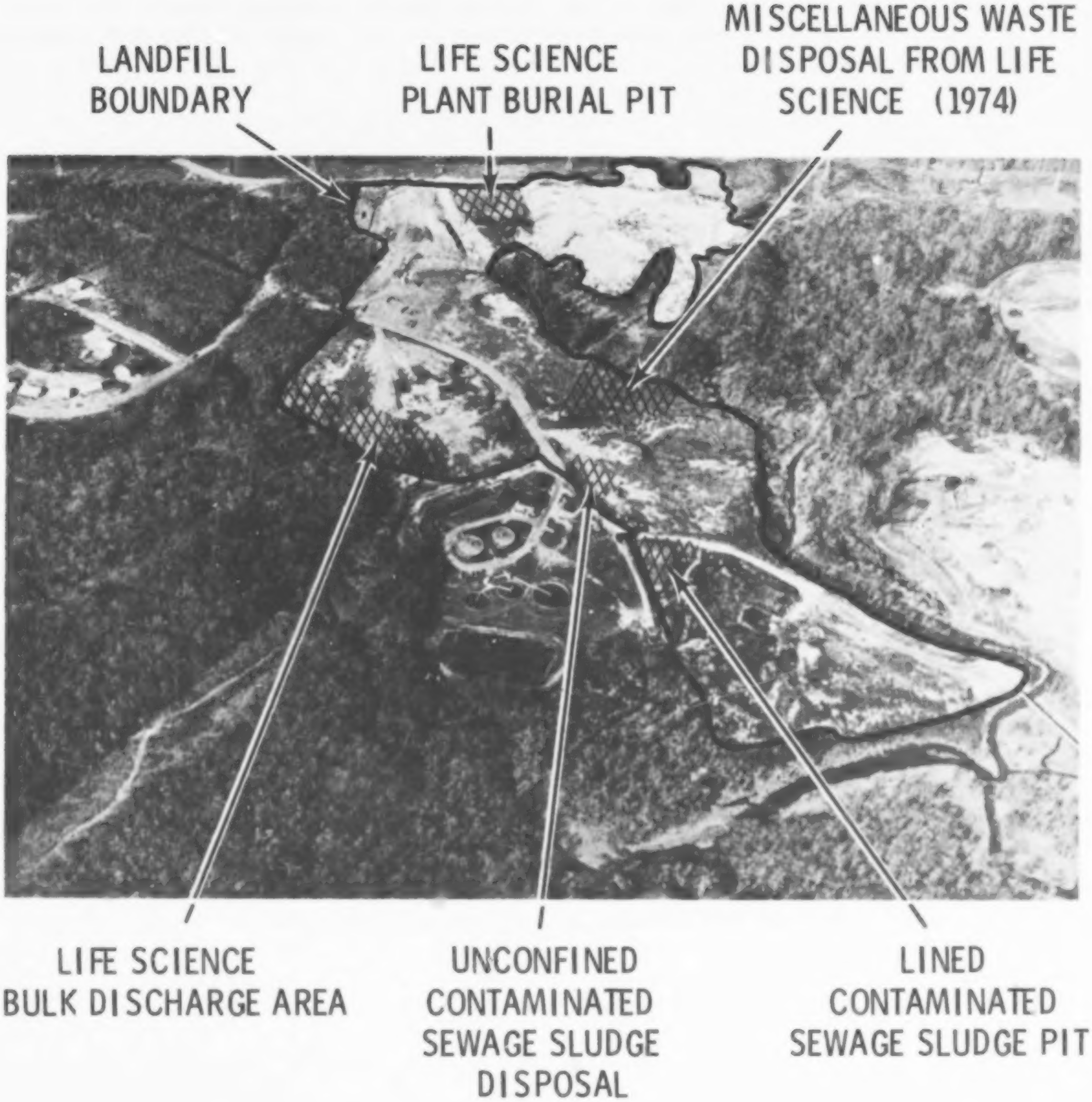

LANDFILL BOUNDARY
LIFE SCIENCE PLANT BURIAL PIT
MISCELLANEOUS WASTE DISPOSAL FROM LIFE SCIENCE (1974)
LIFE SCIENCE BULK DISCHARGE AREA
UNCONFINED CONTAMINATED SEWAGE SLUDGE DISPOSAL
LINED CONTAMINATED SEWAGE SLUDGE PIT

FIGURE V.31. Known and Suspected Deposits of Kepone in the Hopewell Landfill

On November 30, 1977 a series of water samples and cores were collected in an attempt to identify significant Kepone outflows from the landfill. Runoff samples (samples labeled W in Figure V.32) revealed elevated Kepone concentrations below the bulk discharge disposal site. Samples from other suspected or known disposal sites have measurable Kepone levels, but these are comparable to values detected throughout the Hopewell area and therefore do not display surface contamination different from that of nondisposal areas. Of the remaining sites, only two had runoff with Kepone in excess of 1 µg/ℓ (ppb): one below the miscellaneous waste disposal area, and one from the lined sewage sludge disposal pit. No runoff sample was taken in the area around the unconfined sewage sludge disposal site.

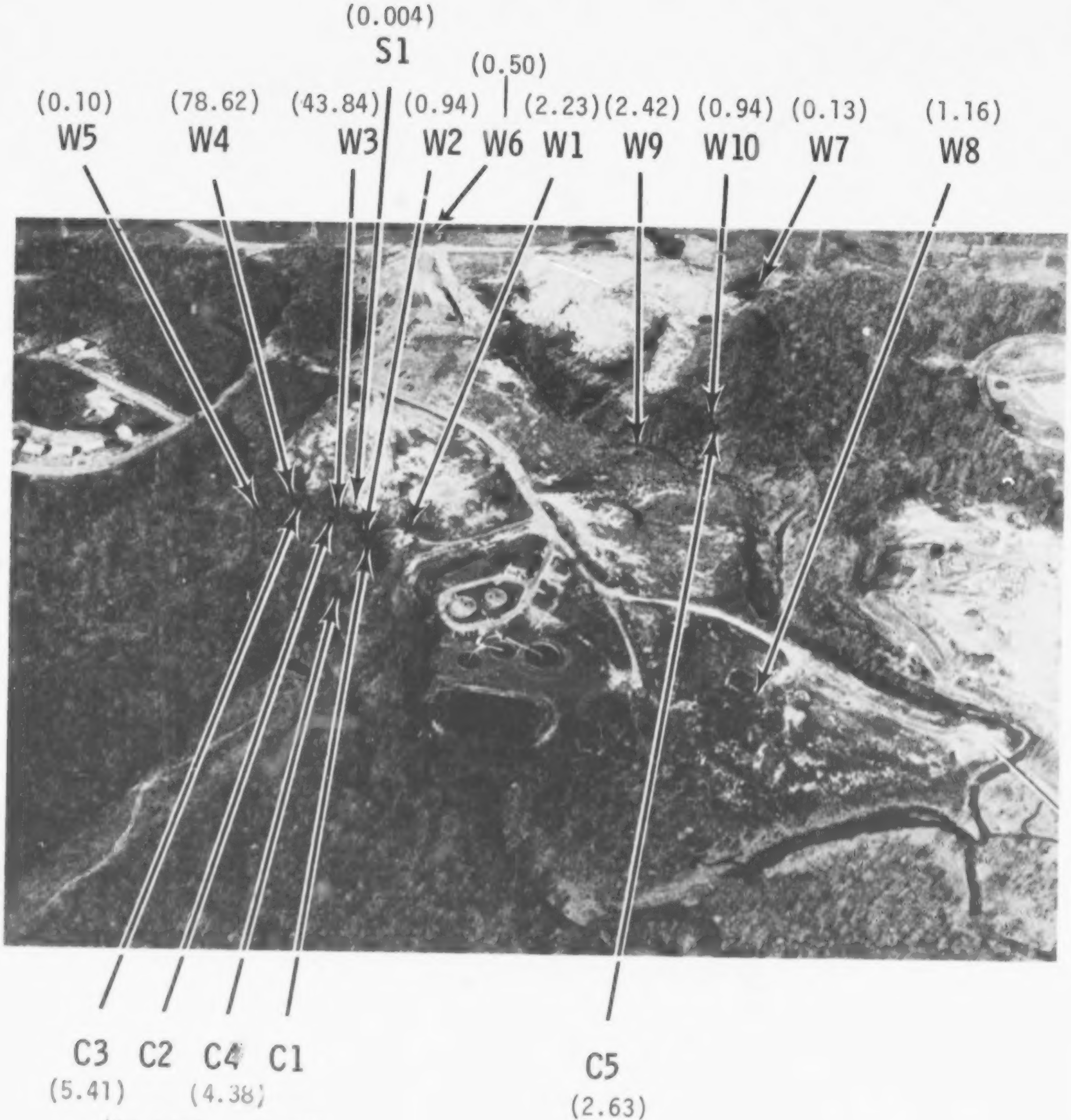
The soil sample taken in the bulk discharge area contained 0.004 µg/g (ppm) Kepone. Results of Kepone analysis for 30 cm (12 in.) cores from the landfill site are presented in Table V.25. The bulk of the contamination occurs in the top 10 cm (4 in.) of soil. One sample, the C2 site, exceeded 1% Kepone. This site corresponds with the high runoff values identified and reflects an area of major discharge. The C5 sample near the miscellaneous disposal area indicates a much lower level of contamination.

A detailed perspective on the location of the affected site is given in Figure V.33. Additional sampling was performed to determine the extent of contamination in the marsh area. Samples included sediment cores, hand-augered soil cores, and grab samples of mud and runoff. The site of each sample is located in Figure V.34.

Concentrations of Kepone found in the surface sediments of these samples are presented in Figure V.35. These ranged from a low of 2.2 µg/g (ppm) to a high of 35,163 µg/g (ppm). A pentagonal section (Figure V.35) approximately 1000 m^2 (0.25 acre) in area contains sediments averaging 12,200 µg/g (ppm) or 1.2% Kepone in the top 4 in. Variations in Kepone concentrations with depth can be seen from Tables V.26 and V.27. Kepone concentrations below an average of a 4-in. depth are roughly an order of magnitude less and quickly drop to levels in the tens of parts per million range. Based on 1000 m^2 (0.25 acre) of sediments (1122 kg/m^3, 70 lb/ft^3 dry) contaminated to an average level of 12,200 µg/g (ppm) in the top 10 cm (4 in.), it is estimated that 1400 kg (3100 lb) of Kepone currently lie in the marsh. This is 78% of the estimated 1800 kg (4000 lb) that were discharged.

Runoff samples contained Kepone at concentrations of up to 53.04 µg/ℓ (ppb):

LFR1 - 1.02 µg/ℓ (ppb)
LFR2 - 0.36 µg/ℓ (ppb)
LFR3 - 0.17 µg/ℓ (ppb)
LFR4 - 53.04 µg/ℓ (ppb)
LFR5 - 14.75 µg/ℓ (ppb)


(0.004)
S1
(0.50)
(0.10)
W5
(78.62)
W4
(43.84)
W3
(0.94)
W2
W6
(2.23)
W1
(2.42)
W9
(0.94)
W10
(0.13)
W7
(1.16)
W8
C3
(5.41)
C2
(10,160)
C4
(4.38)
C1
(0.33)
C5
(2.63)

W - Water samples in μg/l (ppb) Kepone
S - Soil sample in μg/g (ppm) Kepone
C - Core samples in μg/g (ppm) Kepone

FIGURE V.32. Landfill Sampling Locations and Results of Kepone Analysis November 30, 1977

TABLE V.25. KEPONE CONCENTRATIONS IN LANDFILL SOIL CORES (μg/g-ppm)

Core Location	Depth	Kepone Concentration
C1	Top 4 in.	0.33
	Top Mid 4 in.	0.10
	Bottom Mid 4 in.	1.75
	Bottom 4 in.	2.16
C2	Top 4 in.	10,160
	Mid 4 in.	14.58
	Bottom 4 in.	1.46
C3	Top 4 in.	5.41
	Mid 4 in.	1.37
	Bottom 4 in.	1.45
C4	Top 4 in.	4.38
	Mid 4 in.	0.23
	Bottom 4 in.	0.02
C5	Top 4 in.	2.63
	Mid 4 in.	0.63
	Bottom 4 in.	0.58

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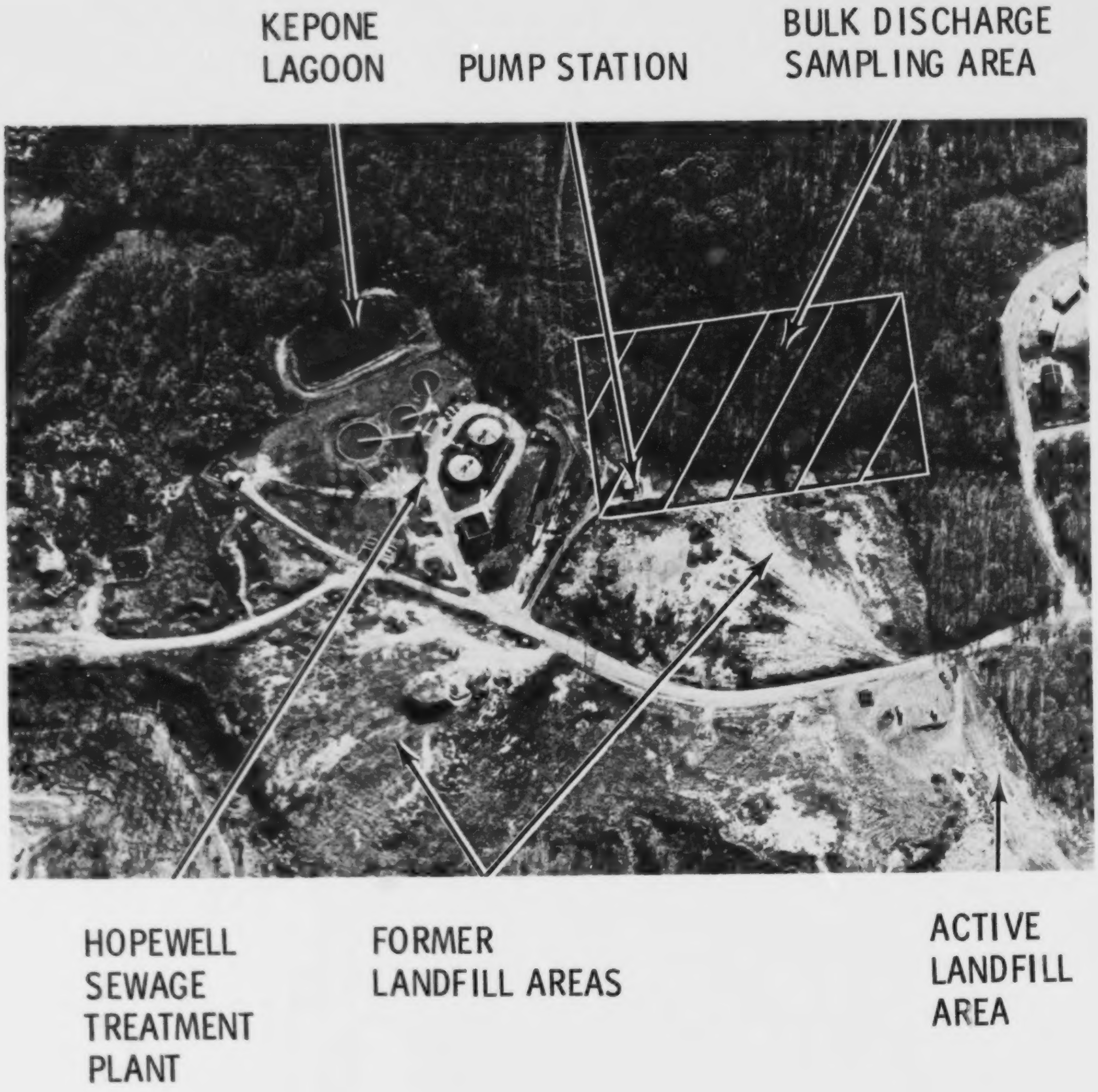
KEPONE LAGOON
PUMP STATION
BULK DISCHARGE SAMPLING AREA
HOPEWELL SEWAGE TREATMENT PLANT
FORMER LANDFILL AREAS
ACTIVE LANDFILL AREA

FIGURE V.33. Location of Marsh Contaminated by Bulk Discharge

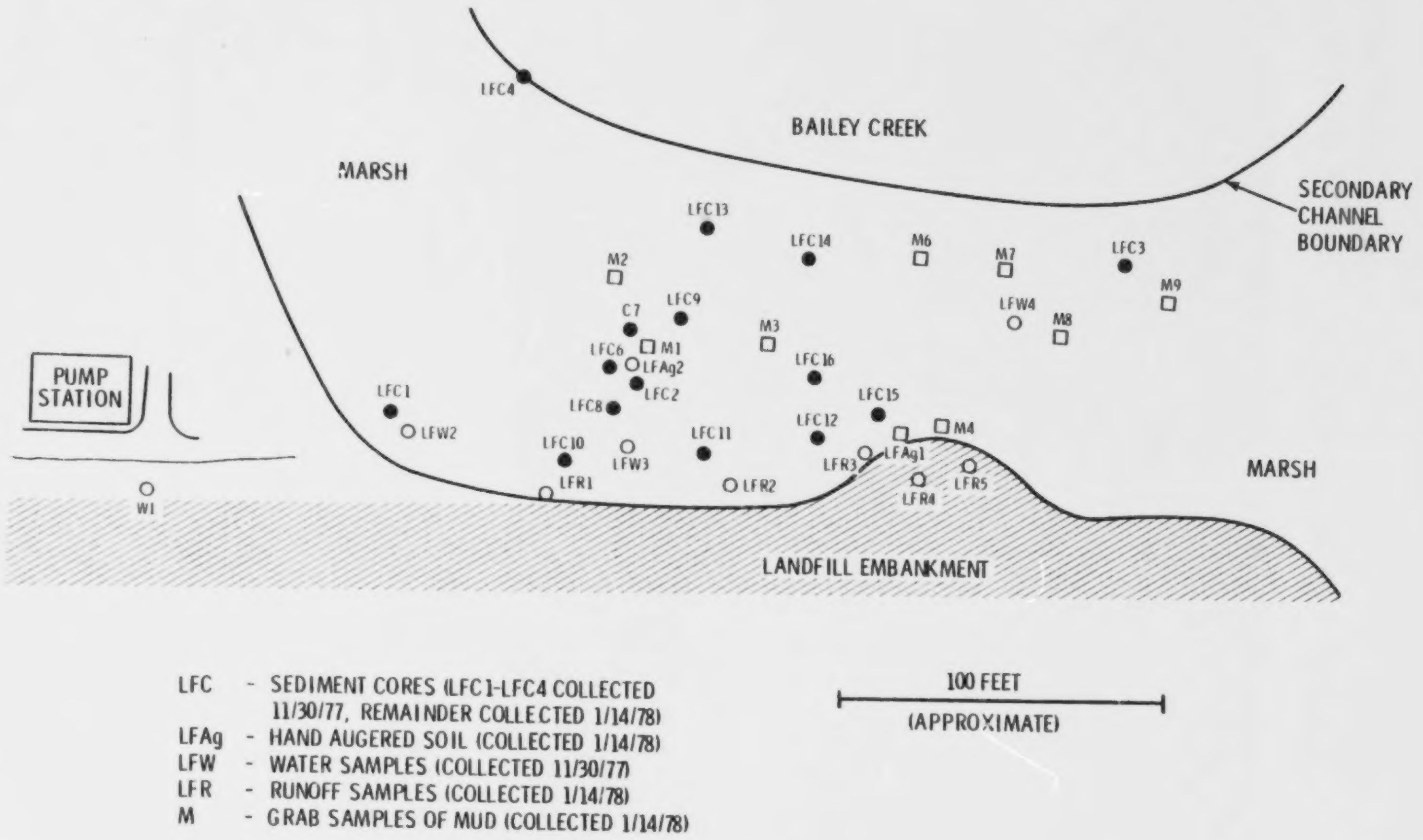
LFC4
BAILEY CREEK
MARSH
SECONDARY CHANNEL BOUNDARY
LFC13
LFC14
M6
M7
LFC3
M2
M9
C7
LFC9
LFW4
M8
M3
LFC6
M1
LFAg2
LFC16
PUMP STATION
LFC1
LFC2
LFC15
LFC8
LFW2
LFC12
M4
LFC10
LFW3
LFC11
LFAg1
LFR3
MARSH
LFR1
LFR2
LFR4
LFR5
W1
LANDFILL EMBANKMENT
LFC - SEDIMENT CORES (LFC1-LFC4 COLLECTED 11/30/77, REMAINDER COLLECTED 1/14/78)
LFAg - HAND AUGERED SOIL (COLLECTED 1/14/78)
LFW - WATER SAMPLES (COLLECTED 11/30/77)
LFR - RUNOFF SAMPLES (COLLECTED 1/14/78)
M - GRAB SAMPLES OF MUD (COLLECTED 1/14/78)
100 FEET
(APPROXIMATE)

FIGURE V.34. Location of Sample Sites in the Marsh Below the Bulk Discharge Area

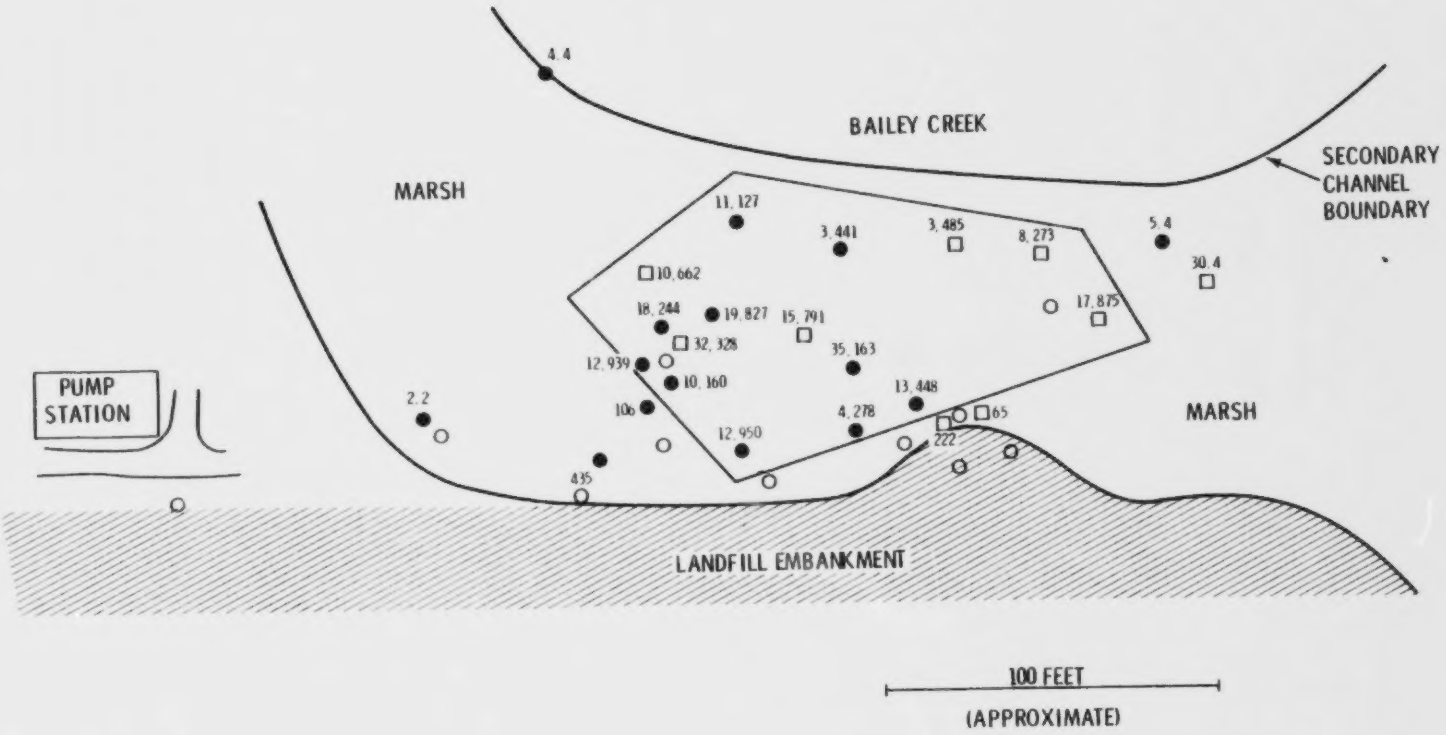
4.4
BAILEY CREEK
SECONDARY CHANNEL BOUNDARY
MARSH
11,127
3,441
3,485
8,273
5.4
30.4
10,662
18,244
19,827
15,791
17,875
32,328
35,163
12,939
10,160
13,448
PUMP STATION
2.2
106
4,278
65
12,950
222
MARSH
435
LANDFILL EMBANKMENT
100 FEET
(APPROXIMATE)

FIGURE V.35. Kepone Levels in Surface Sediment of Marsh and Approximate Boundary of Heavy Contamination

TABLE V.26. KEPONE CONCENTRATION IN AUGER SAMPLES

Depth (ft)	Kepone Concentration (μg/g-ppm) LFAG1	Kepone Concentration (μg/g-ppm) LFAG2
0		
1	11.23	
2	3.25	
3	2.17	
4	0.32	0.69
5	1.27	
6	2.22	0.66
7	1.55	
		1.72
8	0.93	
9	0.72	0.93
		1.29
10	0.51	0.39

The elevated values are associated with the embankment itself. These samples were taken on January 14, 1978 after a rainstorm on January 13. Comparison of runoff values suggests that additional Kepone residues remain in the embankment and that they are less tightly bound in the soil there than in the highly organic sediments of the marsh.

WATER WITHDRAWALS

In evaluating the environmental impacts of Kepone in the Hopewell area it is necessary to establish the uses of affected river water. Also, by knowing the amount and purpose of water withdrawals, potential problems associated with Kepone mitigation alternatives can be identified. Therefore, Tables V.28 and V.29 have been compiled to provide a summary of water diversions from the upper tidal portion of the James River from data on file in the Virginia State Water Control Board files. The location of listed withdrawal facilities is given in Figure V.36.

TABLE V.27. KEPONE CONCENTRATION IN MARSH AREA SEDIMENT CORE SAMPLES

Core Number	Segment Number	Segment Length (in.)	Kepone Concentration (µg/g-ppm)
LFC6	1	2.5	12,939
	2	3.5	253
	3	4.5	9.9
LFC7	1	3.0	18,244
	2	4.0	90.6
	3	3.0	59.8
	4	3.0	17.8
LFC8	1	3.0	15.3
	2	3.0	106
	3	4.5	4.3
	4	5.5	19.9
LFC9	1	4.5	19,827
	2	3.0	237
	3	6.5	16.4
	4	5.5	15.1
LFC10	1	1.0	0.7
	2	4.0	4.6
	3	1.5	435
	4	4.0	7.5
	5	3.5	1.5
LFC11	1	2.0	1.2
	2	3.0	12,850
	3	6.0	1,254
LFC12	1	3.0	4,278
	2	2.5	26.1
	3	2.0	3.6
	4	4.5	13.2
LFC13	1	2.0	7,059
	2	1.0	11,127
	3	2.0	98.1
	4	2.5	35.4
	5	2.5	5.5
	6	7.0	34.9

TABLE V.27. (continued)

Core Number	Segment Number	Segment Length (in.)	Kepone Concentration (μg/g-ppm)
LFC14	1	6.0	3,441
	2	4.5	53.2
	3	2.5	17.3
	4	2.0	2.0
LFC15	1	2.5	13,448
	2	3.0	955
	3	2.5	194
	4	3.0	143
LFC16	1	4.0	35,163
	2	3.0	1,067
	3	4.0	15.1

Initial screening of the uses associated with these withdrawals has shown no areas of concern for human or product contamination. Most of the water withdrawn is used for industrial purposes where water quality is not an important factor. Where the water is used for human consumption or comes in contact with products that are consumed, the water is pretreated to remove contaminants.

One such area where contaminated water is withdrawn for potable use is the water supply system for Hopewell itself. The Virginia American Water Company withdraws an average of 38 MGD from the Appomattox River to serve both industrial and domestic uses in Hopewell. The raw river water is settled and processed through filters. Water is then split with that destined for industrial use going directly to distribution lines while that for domestic use is processed through virgin activated carbon. The flow pattern is illustrated in Figure V.37 along with values obtained for Kepone in each segment using large volume supplies. The solids removal segment of the plant provides for removal of 40% of the Kepone present in raw water. The activated carbon removes on additional 24 to 50%. The Kepone in the backflush water reflects contaminated particulate matter trapped by the carbon. The concentrations of Kepone found here are extremely low. With even excessive human water consumption they would be associated with less Kepone intake by individuals than allowed by current FDA limits for fish.

TABLE V.28. SURFACE WATER WITHDRAWALS WITHIN THE PIEDMONT REGION OF THE JAMES RIVER (BASED ON VIRGINIA STATE WATER CONTROL BOARD'S UNPUBLISHED DATA 1972-1974)

	Name of Plant/Industry	Average Withdrawal Rate (gpd)	Use
1.	Lone Star Industries, Inc. (Kingsland Plant)	2,000,000	2,000,000 - Processing (20,000 consumptive loss)
2.	VEPCO (Dutch Gap)	1,330,500,000	Cooling
3.	Lone Star Industries, Inc. (Jones Neck Island Plant)	1,200,000	1,200,000 - Processing (60,000 consumptive loss)
4.	Lone Star Industries, Inc. (Varina Farms Plant and Curles Neck Plant)	3,400,000	2,680,000 - Processing 100,000 - Evaporation 100,000 - Consumption 520,000 - Direct Contact Processing
5.	American Tobacco Co. (Hamner Div.)	3,000,000	A majority for Processing (Proprietary information)
6.	Allied Chemical Corp.	32,660,000	31,812,000 - Cooling 750,000 - Processing 98,000 - Sanitary
7.	Allied Chemical Corp.	144,000,000	Approximately 130,000,000 - Cooling
8.	Continental Can Co.	20,000,000	20,900,000 - Cooling 19,780,000 - Processing 2,000,000 - Boiler Feed 12,000 - Sanitary (Cooling water is re-used for processing)
9.	VEPCO (Surry)	2,593,100,000	Cooling

TABLE V.29. SURFACE WATER WITHDRAWALS (PUBLIC USE) WITHIN PIEDMONT REGION ON JAMES RIVER BASIN

(1) Name of System	(2) Withdrawal Source	(3) Location or Lat./Long.	(4) Total # Connections	(5) Average Withdrawal Rate (gpd)	(6) Peak Withdrawal Rate (gpd)	(7) Estimated Population Served	(8) Unit Use Coeff. (gpcd)	(9) Storage Capacity (gal)	(10) Treatment Required	(11) Year of Data Base	(12) Projected Demand for 2020 (gpd)	(13) 7-day, 1/10 Year Low Flow (gpd)
City of Richmond Water Filtration Plant	James River	Richmond	53313 Domestic 9200 Commercial 327 Industrial 2760 Surrounding Counties 65600 Total	45,000,000	65,000,000	390,000	115	57,300,000	Aeration Prechlorination Coagulation Sedimentation Filtration Taste & Odor Ammoniation Fluoride Adjustment Disinfection	1974[1]	63,000,000	440,000,000
Va. American Water Corp.	Appomattox River	37 18 77 18	7835 Domestic 823 Commercial 16 Industrial 8674 Total	28,000,000	30,000,000	22,000	1273	4,250,000	Prechlorination Coagulation Sedimentation Rapid Sand Filter Chlorination	1974[1]	37,100,000	44,500,000
St. John Vianney Seminary	James River	37 34 32 77 40 38		10,500	18,750	150	70		Prechlorination Coagulation Sedimentation Filtration Disinfection	1974[2]		407,000,000

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(1) Data obtained via personal communication with plant representative or municipal officials

(2) Data obtained from EPA printout

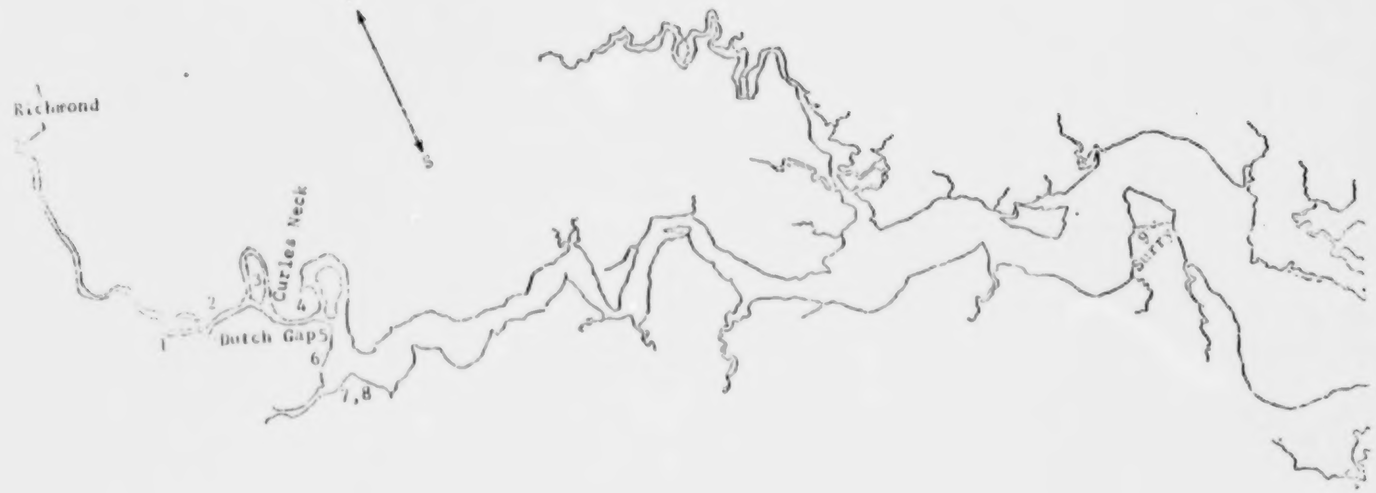
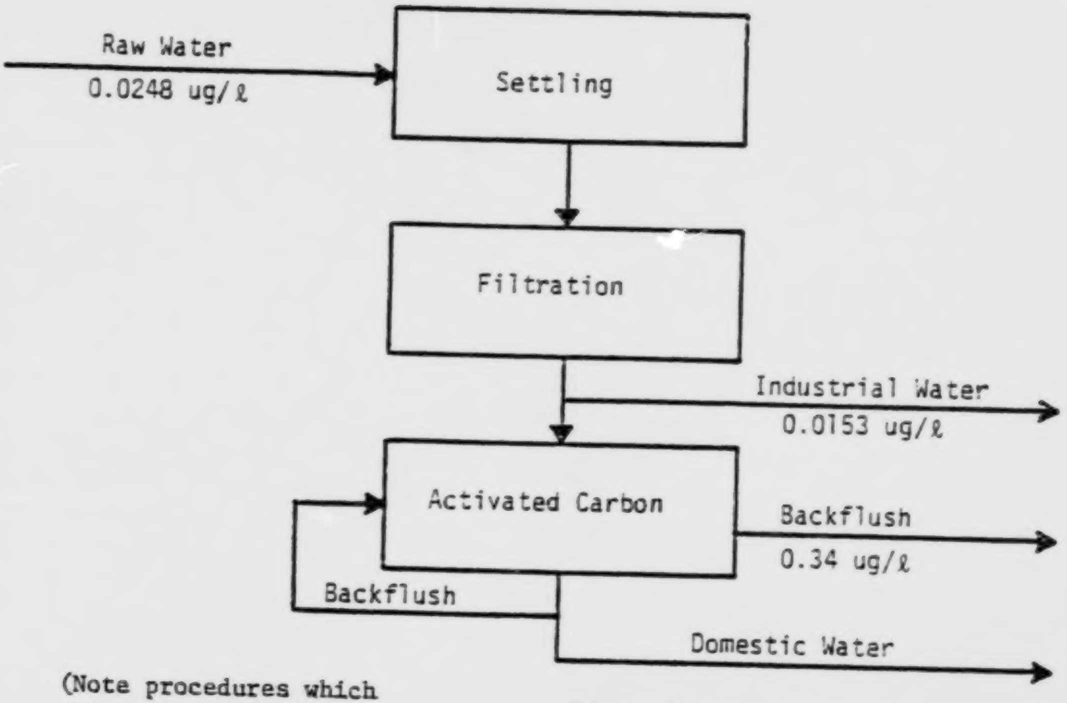

N
S
Richmond
1
2
3
Curles Neck
4
Dutch Gap
5
6
7,8
9
Surry

FIGURE V.36 Plant/Industry Locations Within the Piedmont Region of the James River
(Scale 1:200,000)


Raw Water
0.0248 ug/ℓ
Settling
Filtration
Industrial Water
0.0153 ug/ℓ
Activated Carbon
Backflush
0.34 ug/ℓ
Backflush
Domestic Water

(Note procedures which allowed lower levels of sensitivity for these samples)

Time of Day (9/27/77)	Kepone Concentration (ug/ℓ)
0900	0.0091
1205	0.0024
1515	0.0070

FIGURE V.37. Flow Pattern and Kepone Content of Hopewell Water Supply

COMPOSITE PROFILE OF KEPONE - HOPEWELL

The description of Kepone residuals in the Hopewell area and the delineation of their movement is a very complex undertaking. From the data provided in preceding sections, it is difficult to select a single consistent set of observations to support a comprehensive problem statement. Evidence, however, does support a most probable scenario.

Sewage Treatment Plant

It appears that residuals in the surface soils currently form the greatest continuing source of Kepone to the river. Periodically Kepone is dissolved and joins particulate sorbed Kepone washed from the soil in storm runoff. Some of this enters the sewage system. Such pulse inputs stimulate peak outflows of Kepone from the treatment plant but also are stored by the bacterial growths in the sewers. Hence, the sorptive capacity of these solids tends to smooth the peaks and valleys in Kepone concentration. The treatment plant itself also smooths the absolute discharge levels by sorption on sludge and recycle through digester supernatant. In effect then, the sewer and sewage treatment plant function as a large, mixed reactor into which chronic low level inputs flow spiked by periodic pulses. Kepone appears in wastewater from all segments of the sewer system as a result of buildup formed during the 1974-1975 production period. The importance of stormwater runoff to inflows of Kepone to the sewer system is demonstrated by the data from the Life Science Products plant on May 4, 1977.

Soil

Kepone enters Bailey Creek from desorption of Kepone associated with contaminated soil and sediments as well as contaminated ground water affected by leachate from the landfill area and the disposal lagoon. These levels are augmented sharply during periods of high precipitation and subsequent runoff. Though subject to tidal influence, the contaminated Bailey Creek water provides a continuous input of Kepone to Bailey Bay. Desorption stimulated by high pH wastewater has slowly depleted surface sediment concentration. The released Kepone is carried to the River where buffering action and dilution creates an environment conducive to readsorption on suspended and fixed sediments. The total load of Kepone transferred in this manner will decline with use of the new regional treatment plant since secondary treatment will sponsor uptake solids which will subsequently be removed. Even with this reduction, it will take many years (>50) for Bailey Bay to be cleansed by natural forces.

Pebbled Ammonium Nitrate Site and Landfill

Three specific sources of Kepone were identified for particular attention: the Kepone sludge lagoon, the Pebbled Ammonium Nitrate (PAN) site, and the landfill. The lagoon does not contain significant quantities of Kepone. It does appear to be leaking, however, and therefore may provide continuing inputs to Bailey Creek. Large deposits of Kepone were suspected at the PAN site but analyses have not confirmed their presence. Over 1350 kg (3000 lb) of Kepone have been identified in a marsh below the Hopewell landfill. Analysis reveals that this Kepone is mobilized in leachate. The landfill is the only site located to date with potential quantities of Kepone which are significant when compared to existing residuals in the James River.

James River

To put the Hopewell area data in perspective an estimate has been made of total current Kepone deposits in James River sediments. They amount to an average estimate of 9600 kg (21,000 lb) and a maximum estimate of 19,000 kg (42,000 lb). Calculations are based on data provided in Appendix B. These total quantities compare favorably with an independent estimate of 11,000 to 18,000 kg (25,000 to 40,000 lb) developed by VIMS (1977). A synopsis of pertinent inputs to the calculations is provided in Table V.30.

A summary of estimated Kepone residuals is provided in Table V.31.

TABLE V.30. BASIS FOR ESTIMATE OF KEPONE DEPOSITS IN JAMES RIVER SEDIMENTS

	Bailey Bay	Jordan Point to Turkey Island	Jamestown to Jordan Point	Newport News to Jamestown Island	Hampton Roads	Total
Area	800 acres	3.3 mi^2	44.9 mi^2	132.7 mi^2	60.9 mi^2	243.1 mi^2
Mean concentration μg/g-ppm	0.91	0.07	0.15	0.08	0.023	
Mean + one standard deviation μg/g-ppm	3.31	0.21	0.28	0.15	0.0375	
Volume (ft^3) assumes 1 ft depth	3.5×10^7	9.2×10^7	1.25×10^9	3.7×10^9	1.7×10^9	6.8×10^9
Mass of dry sediments (lb)(assumes 70 lb/ft^3)	1.3×10^9	3.48×10^9	4.7×10^{10}	1.4×10^{11}	6.4×10^{10}	2.5×10^{11}
Mean total Kepone (kg)	537	110	3,204	5,091	670	9,612
(lb)	1,183	243	7,050	11,200	1,472	21,148
Maximum total Kepone (kg)	1,956	332	6,000	9,545	1,091	18,924
[mean + std. deviation](lb)	4,303	730	13,160	21,000	2,400	41,593
Number of sample sites	25	9	66	66	39	205
Number of points with <0.02 μg/g Kepone	3	3	5	13	21	45
Sampling density (points/mi^2)	20	2.7	1.5	0.5	0.64	

Assumes 12 in. depth at mean even though some samples were analyzed to depths less than 12 in. Since concentrations decline with depth, estimate here is conservative.

TABLE V.31. ESTIMATE OF KEPONE RESIDUALS INCLUDING MATERIAL DRUMMED AT THE LIFE SCIENCE PRODUCTS PLANT AFTER CLOSURE (DECEMBER 1977)

Residing In	Estimated Quantity of Kepone	
	kg	lb
Sewer System	23	50
Surface Soil (1 in.)	45-450	100-1,000
Kepone Sludge Lagoon	100	220
Bailey Bay Sediments*	540-2,000	1,200-4,300
James River Sediments*	9,000-17,000	20,000-38,000
Drums at Hopewell	9,400	20,700
Drums at Portsmouth	13,000	28,800
Landfill†	1,400	3,100
Pebbled Ammonium Nitrate Plant Site	100	220
Rounded total*	33,700-43,600	73,500-95,500

---

* Low value reflects estimate extrapolated from mean concentrations, high value reflects estimates based on mean plus one standard deviation.

† Includes identified deposits only.

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CHAPTER VI - ECOLOGICAL PROFILE OF THE JAMES RIVER

SUMMARY

Content

Chapter VI provides an overview of the aquatic ecology of the James River system. It begins with a description of the river system including salinity distribution, temperature, and turbidity levels. This is followed by a discussion of the ecosystem in each of four zones of the James extending from Turkey Island (slightly upstream of Hopewell) to its mouth at Chesapeake Bay. Descriptions are given of the significant elements of the food chain, as well as of commercially important species. The chapter concludes with an estimate of summer and winter biomass levels for various finfish species in the James River as developed by the Virginia Institute of Marine Science.

Findings

- James River species and their distribution through the tidal portion of the River are summarized in Appendices D and K.
- The Virginia Institute of Marine Science estimates total summer biomass of finfish in the James River (RM 0-45) to be 1.65×10^6 kg (3.4×10^6 lb).

GENERAL FEATURES

The James River is the largest of Virginia's four major river systems. It flows for more than 680 km (420 mi) from its headwater to the Chesapeake Bay. Its drainage basin covers approximately 26,000 km^2 (10,000 mi^2) in Virginia and West Virginia, with the majority in Virginia. The tidal reach extends to Richmond, about 180 km (110 mi) upstream from its mouth at Hampton Roads. The River discharges past Richmond at an average rate of 212 m^3/sec (7,500 cfs).

In view of the scope and objectives of this study the area covered in this report is restricted to the tidal portion of the River from Turkey Island near Hopewell to the mouth at Chesapeake Bay, a distance of approximately 131 km (80 mi) (Figure VI.1). Three main tributaries, the Appomattox, Chickahominy and Nansemond Rivers, are not included in this study.

The study area (Figure VI.2) can be divided into four salinity regimes as follows (Boesch, 1973; Diaz, 1977):

Lower Tidal Fresh water:*	River Mile (RM) 40 - 80 Average Salinity 0 - 0.5 g/ℓ (ppth)
Oligohaline:	RM 25 - 40, Average Salinity 0.5 - 5 g/ℓ (ppth)
Mesohaline:	RM 12-25, Average Salinity 5 - 15 g/ℓ (ppth)
Polyhaline:	RM 0 - 12, Average Salinity >15 g/ℓ (ppth)

The tidal James River has long been utilized for commercial and sport fishing (Figures VI.3 and VI.4). Fishery resources are very diverse and productive as the river abounds in fresh-water and marine fish. The commercial fishing grounds extend to near the Hopewell area. The fresh-water and upper portion of brackish water zones are extensively utilized by anadromous fish as spawning and nursery grounds. The lower estuary is a very productive shellfish zone. Due to Kepone contamination, the River was closed to the harvesting of finfish and shellfish in December 1975. As of Septemper 16, 1977 the closure exempted female hard crabs seaward of the James River Bridge, but closed off taking of all male crabs in the southern portions of Chesapeake Bay near the mouth of the James River (See Appendix J).

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*This constitutes the lower segment of the tidally influenced fresh-water portion of the James River.

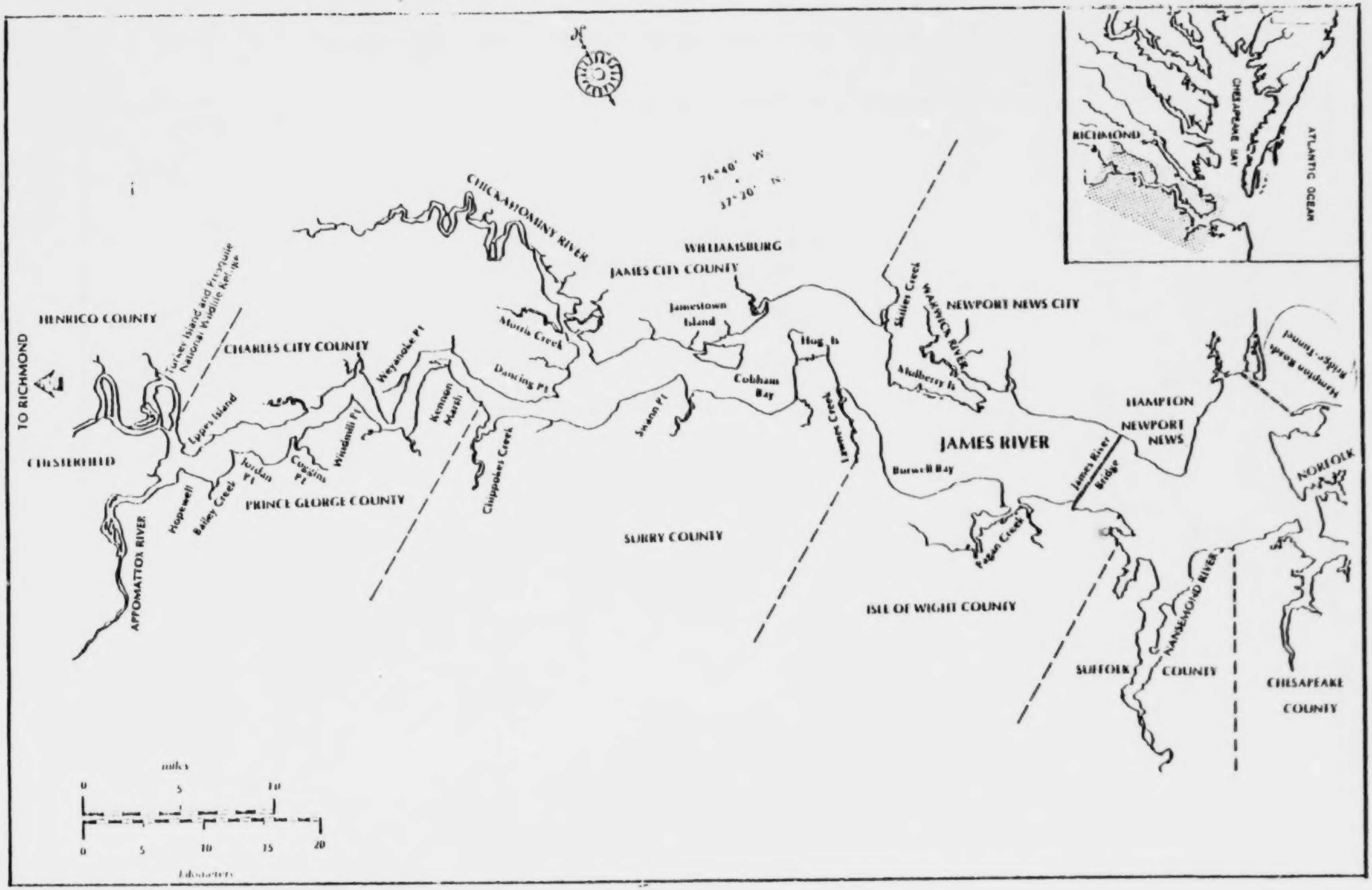
ATLANTIC OCEAN
CHESAPEAKE BAY
RICHMOND
76°40' W
37°20' N
CHICKAHOMINY RIVER
WILLIAMSBURG
JAMES CITY COUNTY
Jamestown Island
NEWPORT NEWS CITY
WARWICK RIVER
Skiffes Creek
Mulberry Is
Hampton Roads Bridge-Tunnel
HAMPTON
NEWPORT NEWS
NORFOLK
JAMES RIVER
James River Bridge
Burwell Bay
Pagan Creek
Hog Is
Lawnes Creek
Cobham Bay
Swann Pt
Morris Creek
Dancing Pt
Chippokes Creek
Kennon Marsh
Weyanoke Pt
Windmill Pt
Coggins Pt
Jordan Pt
Bailey Creek
Hopewell
Eppes Island
Turkey Island and Presquile National Wildlife Refuge
HENRICO COUNTY
CHARLES CITY COUNTY
TO RICHMOND
CHESTERFIELD
APPOMATTOX RIVER
PRINCE GEORGE COUNTY
SURRY COUNTY
ISLE OF WIGHT COUNTY
NANSEMOND RIVER
SUFFOLK COUNTY
CHESAPEAKE COUNTY
miles
0
5
10
0
5
10
15
20
kilometers

FIGURE VI.1. Location of Geographic Features

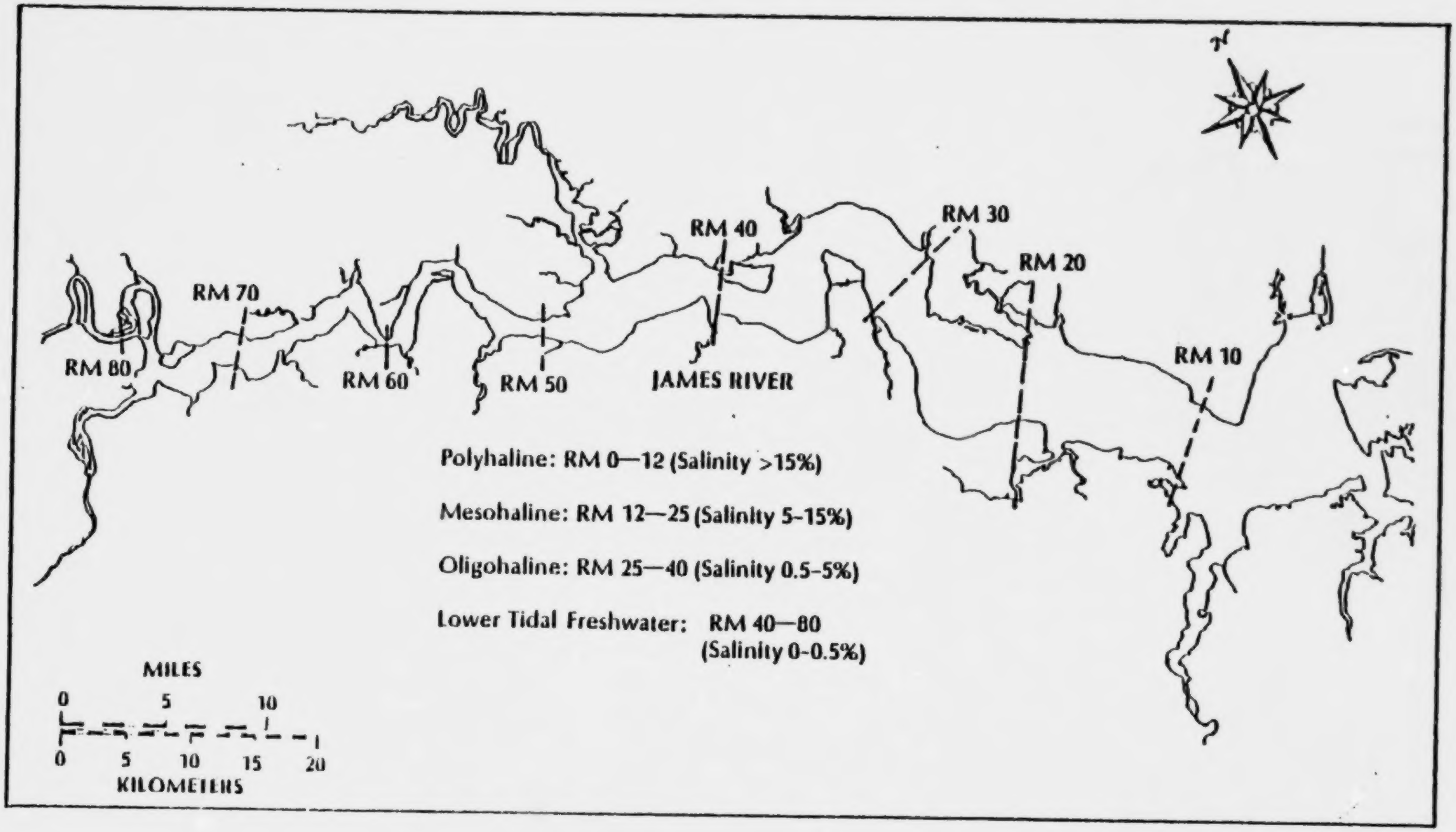
N
RM 80
RM 70
RM 60
RM 50
RM 40
JAMES RIVER
RM 30
RM 20
RM 10
Polyhaline: RM 0—12 (Salinity >15%)
Mesohaline: RM 12—25 (Salinity 5-15%)
Oligohaline: RM 25—40 (Salinity 0.5-5%)
Lower Tidal Freshwater: RM 40—80 (Salinity 0-0.5%)
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE VI.2. Four Salinity Zones (Boesch, 1973; Diaz, 1977)

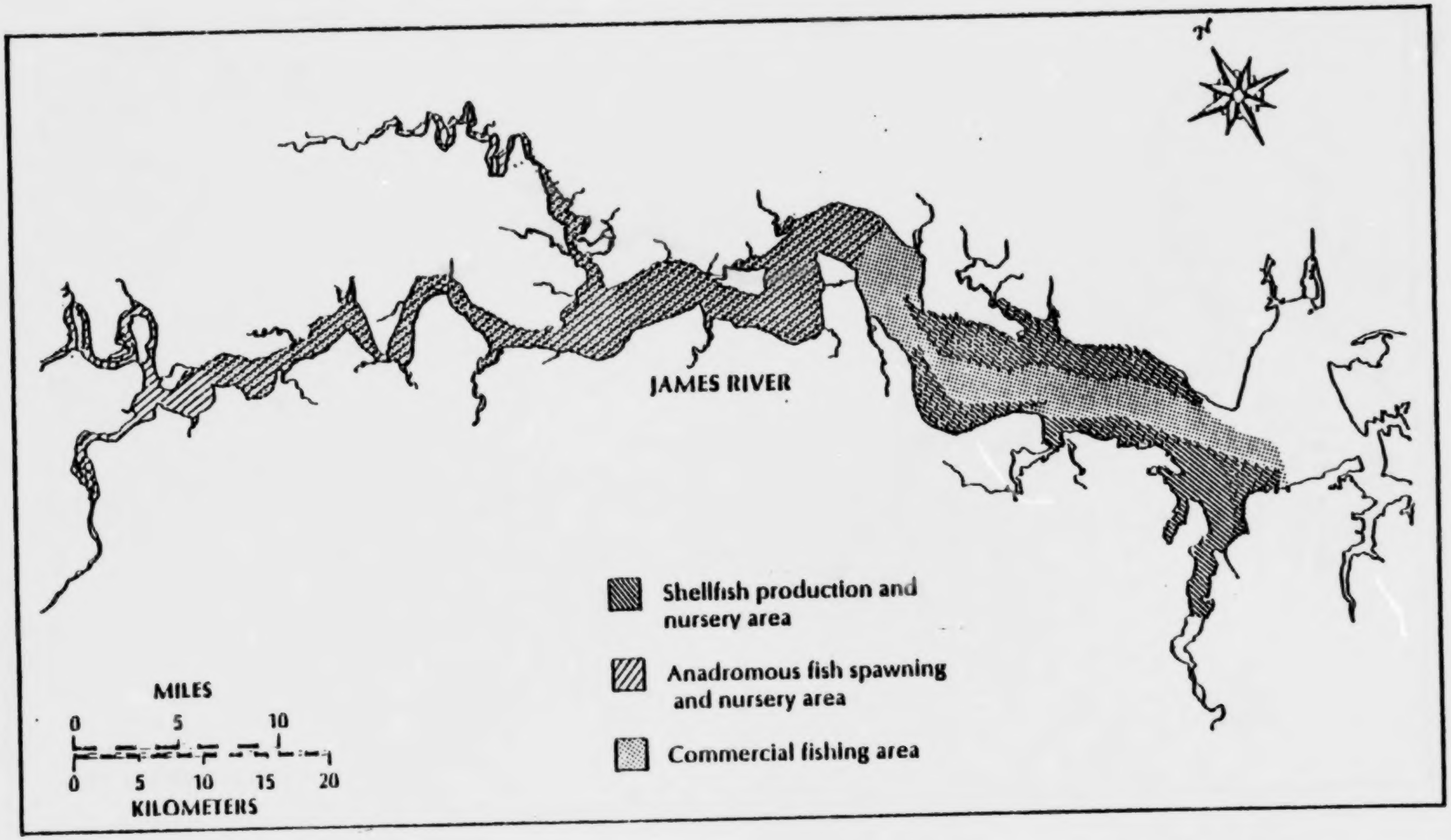
JAMES RIVER
▩ Shellfish production and nursery area
▨ Anadromous fish spawning and nursery area
░ Commercial fishing area
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE VI.3. Fishing, Spawning and Nursery Areas for Fish and Shellfish (U.S. Army Corps of Engineers, 1974)

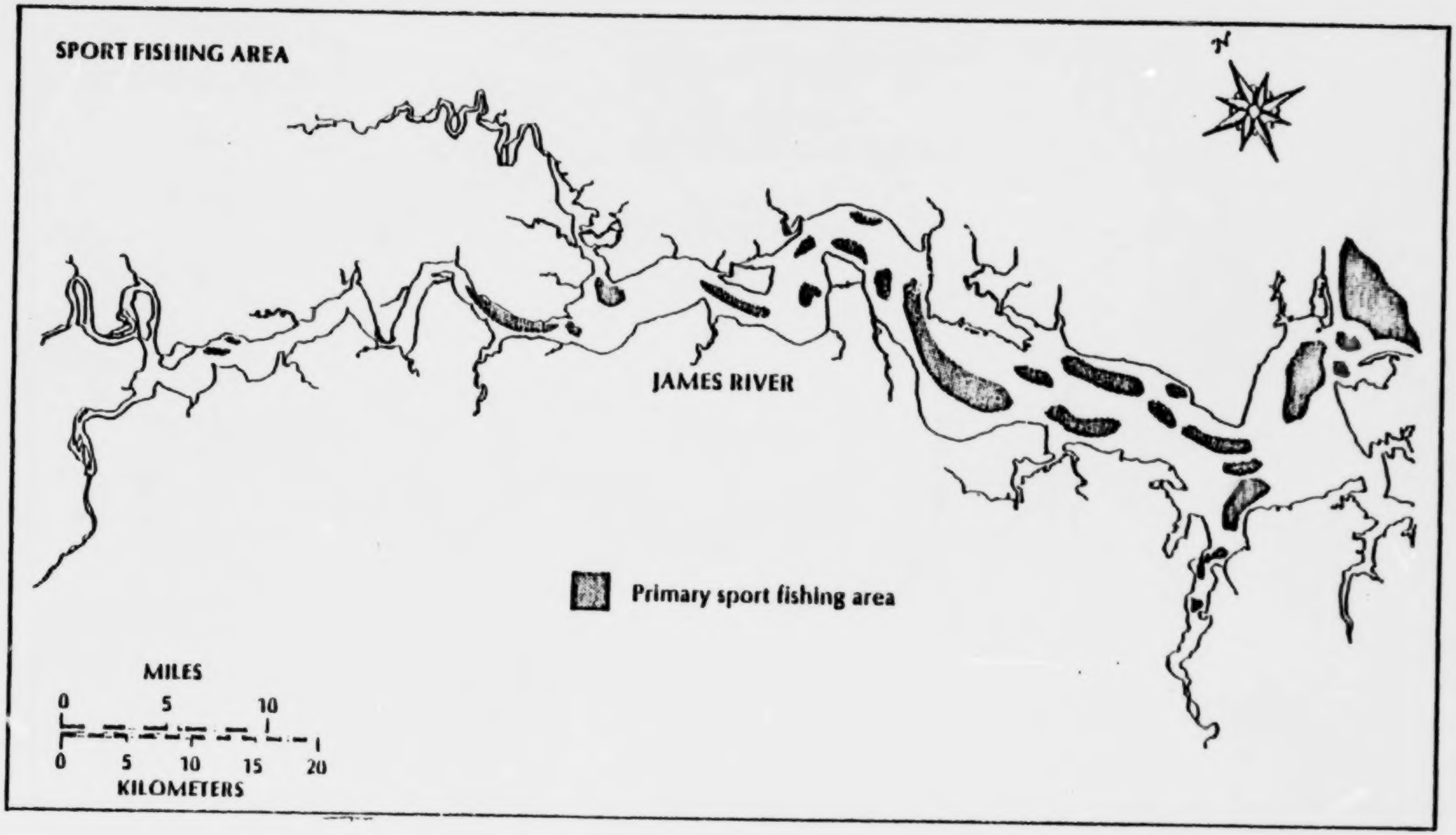
SPORT FISHING AREA
N
JAMES RIVER
▨ Primary sport fishing area
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE VI.4. Primary Sport Fishing Areas (U.S. Army Corps of Engineers, 1973)

Shad, herring, catfish, turtles and elvers are also exempted from the closure. A manuscript of the State order can be found in Appendix J. The river presently is open to the taking of seed oysters (Owen et al., 1976c).

CHARACTERISTICS OF THE MAJOR TRIBUTARIES

Appomattox River

The Appomattox River enters the James River at Hopewell with its waters originating primarily in the Piedmont section of Virginia. The River is dammed 11 km (7 mi) above the fall line at Petersburg. This has created Lake Chesdin. Below Petersburg, the Appomattox flows slowly. Diversity of biota is relatively high in the upper reaches of the River and green algae are the major phytoplankton component. Below the dam diversity is low and in the tidal reaches of the River the dominant algae are the blue-greens. Fish species are similar to those in the James River with catfish assuming year-round importance. A nursery area exists for striped bass. Shad and herring also exist below the dam at Lake Chesdin. The organisms present below the dam are primarily those which are tolerant of pollution. Tidal currents, add pollution from the James River.

Chickahominy River

The Chickahominy is a shallow sluggish stream with an impounded lake and tidal fresh-water portions. Above U.S. 60, the river is slow-flowing with fresh-water swamps, and has numerous channels and pools. It receives sewage effluent from Richmond via tributaries. Below the U.S. 60 bridge, the River is less swampy and has more fresh-water marshes. The Chickahominy has a total of approximately 5,670 hectares (14,000 ac) of marshes that are intensely used by waterfowl. Benthic diversity is higher in the Chickahominy than in the James or Appomattox with more clean-water species present. The River supports a luxuriant growth of aquatic plants. Fish species in the Chickahominy are similar to those in the James. Catfish are very abundant and the River is an important spawning and nursery ground for herring and shad. Overall Chickahominy water quality is good.

Nansemond River

The Nansemond River is a short tidal tributary about 26 km (16 mi) long which enters the James at Hampton Roads. Its flow is regulated by supply reservoirs at its headwaters and little fresh water is released except during storms or when the reservoirs are full. As a result, salinity variations are considerable. Salinity is 0-12 ppth in the upper parts and 15-20 ppth at the mouth of the Nansemond.

SALINITY DISTRIBUTION

The James River is a typical coastal plain estuary in which the salinity decreases as the distance upriver from the mouth increases (Figure VI.2). Tidal cycle in the mouth of the River is semi-diurnal with two high tides and two low tides occurring in an approximate 24-hr period. The mean tidal range is 0.76 to 0.9 m (2.5 to 3 ft) in the first 32 km (20 mi) and less than 0.3 m (1 ft) at RM 50. The velocity of the tidal wave is about 18 km/hr (11 mi/hr-16 ft/sec).

The river transport is a function of fresh-water flow and tidal movement. Usually, there is a net downstream transport in the upper, less saline layer and a net upstream transport in the lower, more saline layer. The salt water extends approximately 64 km (40 mi) upstream from the river mouth, although this boundary limit varies considerably depending upon the volume of river flow. It is reported that salt water may extend up to 120 km (74 mi) upstream (near Hopewell) during drought conditions, while fresh water reaches downstream to RM 23 (Weiss and Wilkes, 1974). During the Tropical Storm Agnes in 1972, the fresh-water flow almost reached RM 10, the upper portion of the polyhaline zone (Larsen, 1974). The 21-year average salinity distributions from 1944 to 1965 show that the fresh-salt water interface occurs at RM 30 during the months of March-May and at RM 40 during the November-February months (Figure IV.5).

The salinity increases with depth, although no strong stratification exists. The differences in salinity between surface and bottom waters increase during the months of high river flow. The seasonal salinity differences are more pronounced at the river mouth and are less pronounced upstream. Surface water salinity varies greatly by season as a result of fluctuating river discharges. For example, at RM 23, the salinity varies between 3 and 14 ppth. The isohaline moves 18 mi back and forth along the River (VIMS, 1973).

TEMPERATURE AND TURBIDITY

The water temperatures in the James River during a 1-year period varied between 6 and 28°C at RM 80; 6 and 25°C at Hampton Roads (VIMS, 1973). Generally temperatures in the upper river were slightly higher (up to 7°C higher in summer) than in the lower estuary except in winter. During the winter, the temperature at the mouth of the river was 2°C greater than that at RM 80. Surface and bottom water temperatures were nearly uniform throughout the River.

The turbidity of James River is very high throughout most of its length. The minimum water transparencies measured by Secchi discs were observed in the area between RM 50 and RM 80, where the DO sag usually occurs (VIMS, 1973). The transparencies in the lower 32 km (20 mi) of the James estuary ranged from 0.6 to 2.4 m (2 to 8 ft) which is typical of many estuaries around the Chesapeake Bay. Maximum turbidity, however, generally occurs at the saline and fresh-water interface near Hog Island. Total suspended solid (sediment) concentrations near surface water were greatest in an area between RM 30 and RM 35, averaging approximately 60 mg/ℓ (ppm). The total suspended matter at Hampton Roads was 10 mg/ℓ (ppm) (Nichols, 1972).

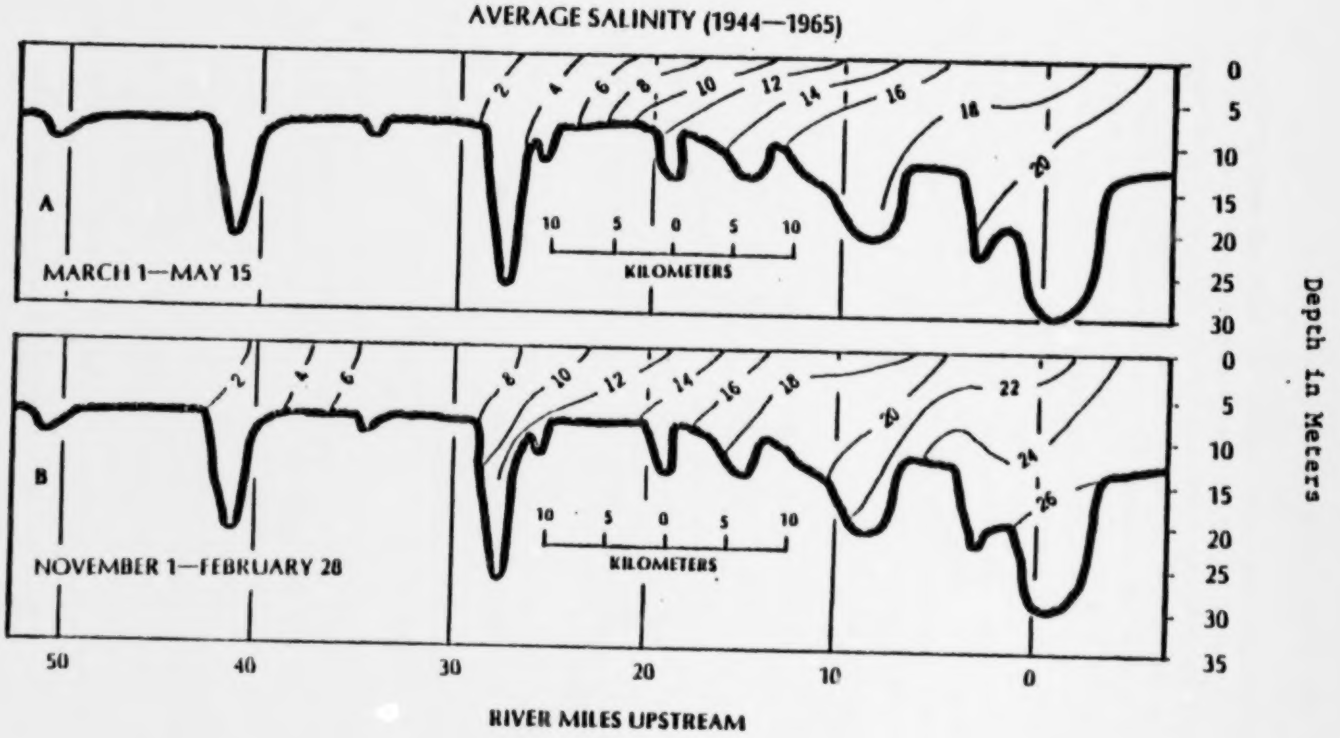

FIGURE VI.5. Salinity Distribution (Nichols, 1972)

ECOLOGY OF THE TIDAL JAMES RIVER

To understand the full impact of current and projected distribution of Kepone in the James River, it is necessary to identify the species present in various reaches and the extent of this habitat. Consequently, an effort was initiated to describe the ecological profile of the tidal James. The tidal James River biota was mapped from the available literature sources, mainly studies by scientists at the Virginia Institute of Marine Science and personal communications with appropriate State, Federal, and local officials. Major emphasis is on the location of fisheries and spawning grounds of ecologically and commercially important species. In addition to the distribution and productivity (when available) of the fisheries, distribution maps were prepared for chlorophyll-a, invertebrates, vertebrates, and selected birds. The vascular flora and plankton are described but not mapped. Comprehensive lists of fauna and flora are presented in Appendix D.

Overview of Previous Studies

The literature collected and reviewed for this ecological study consists of over 150 documents. The Virginia Academy of Sciences (1950), James River Project Committee, published an extensive review of the natural and human resources of the James River Basin. Since that time, over 50% of the literature used in this study has been generated from the Virginia Institute of Marine Science. The bibliography by Barrick et al. (1971) was extremely helpful as well as the printouts updating this bibliography done by the library staff at VIMS.

Twenty-five other organizations have contributed to the James River ecological literature (Table VI.1). It is difficult to meaningfully tabulate the literature because numbers of documents do not reflect quality or quantity of material included, nor does the name of the organization reflect the possibility of interagency funding and cooperation.

Biomass estimates for specific species in the James River system are particularly difficult to develop. However, personnel at VIMS have been able to derive working numbers based on extrapolation from trawl studies and mollusc inventories. A brief description of the VIMS procedures follows:

> Summer Survey - Estimates of finfish biomass in the James during the summer season were based upon catches made during the 1977 ichthyology summer trawl survey in the James River made with the R.V. Brooks towing a 16-ft semi-balloon trawl. Stations surveyed were selected randomly from stratified categories. All catch and weight data were kept separated by species, depth station and river miles from the mouth. Biomass for individual species was computed from weights which were summed within each depth and mile "block." Mean catches for each block were then computed. To illustrate, consider the computation for a shoal area between miles 0-15 where the actual catch of spot was 4628 grams in 23 tows, or 201 g/tow. There were 207 possible sites in this stratum which could have been sampled, hence the total projected weight would be

201 g x 207 sites or 41,600 g. This total must then be adjusted to account for the percentage of quarter square mile that a 16 ft net towed for a quarter of a mile will cover, or 1,742,400 ÷ (16 ft x 1320 ft) ≈82. Hence the adjusted total is 41,607 x 82 or 3,411,744 g (7515 lb). These adjusted totals were then summed for each of five strata to generate the estimate of total biomass for spot at miles 0-15 Subsequently, all river segments were totaled and multiplied by final adjustment factors of 1.8 to account for the catch efficiency of a 16-ft trawl to that of a 30-ft trawl.

Winter Survey - The method of estimation for winter populations was much the same as that previously described for summer populations. However, a 9-m (30-ft) semi-balloon otter trawl was employed with 0.6 x 1.2 m (2 x 4 ft) wooden trawl doors and a 9 m (30 ft) (each leg) bridle. This swept an area of 1727 m^2 (18,590 ft^2) at each station. Estimates were made from surveys during 1973, 74 and 75.

Molluscs - *Rangia* clam populations were estimated utilizing the data of Diaz (1977) and Jordan et al. (1976). Survey data yielded estimates of clam density in segments at 9 km (5 nautical mile) intervals. Extrapolation relied on the assumptions that density was homogeneous over the river bottom and equal to the average of three samples taken in a segment. It was further assumed that clams have an average weight of 0.25 g (5.5×10^{-4} lb). *Corbicula* clam biomass estimates were similarly derived from the data of Diaz (1977) based on a survey conducted in the fall of 1972. An average weight of 0.1 g/clam was employed for extrapolation purposes.

Aquatic Ecology

Because of its estuarine habitats, the biotic communities in the tidal James River are highly complex and diverse in community structure and species composition. They are comprised of typical marine forms in the polyhaline zone, marine and estuarine forms in the meso-oligohaline zones, and freshwater and estuarine species in the tidal fresh-water zone.

The diversity and richness of the benthic populations are typical of this type of estuary, that is, highest in the polyhaline zone and lowest in the oligohaline zone (Diaz, 1977; U.S. AEC, 1974). Populations increase considerably at the lower part of the fresh-water zone (RM 40-55), but decrease further upstream (Figure VI.6).

Phytoplankton biomass (chlorophyll-a level) was greatest in the Hopewell area (Figure VI.7) at more than 40 μg/ℓ (ppb) but was less than 10 μg/ℓ (ppb) for much of the estuary - RM 10-52. (VIMS, 1973; Brehmer, 1972). Among the environmental factors that affect algal productivity and distribution are salinity, water transparency, temperature, and herbivore activity.

TABLE VI.1. BIOLOGICAL-ECOLOGICAL STUDIES OF THE JAMES RIVER BY ORGANIZATIONS

Organization	No. of Documents	Subject
Audubon Society (annual bird censuses)	20	Birds
Battelle Columbus Labs	1	Thermal modeling
College of Wiliam and Mary	1	Floristics
Engineering Science Company	2	Water quality
Gates (W.E.) & Associates	1	Water quality
Johns Hopkins University	2	Thermal ecology, natural resources
Longwood College	1	Floristics
Old Dominion College	2	Water quality
Roanoke College	1	Freshwater fish
U.S. Army Corps of Engineers	5	Water quality, disposal, floristics, floods, resources, dredging
U.S. Atomic Energy Commission (former agency)	4	Surry environmental
U.S. Fish and Wildlife Service	3	Birds
U.S. Geological Survey Water Resources Division	2	Water supply
U.S. National Aeronautics and Space Administration (NASA)	1	Photography
U.S. National Oceanic and Atmospheric Administration (NASA)	3	Tides, data bases, flora
University of Virginia	1	Alewife
Virginia Agricultural Experiment Station	1	Flora
Virginia Game and Inland Fisheries Commission	8	Endangered species
Virginia Council Environmental Quality	1	Advisory
Virginia Department Highway and Transportation	1	Fisheries
Virginia Electric and Power Company (VEPCO)	1	Surry environment
Virginia Institute of Marine Science (VIMS)	71	Fishes, clams, macrobenthos, thermal, hydrography, crustacea, eels, water quality, algae, foraminifera, sediments, plankton, shrimp, oysters, wetlands, Surry environment, Windmill Point sewage, floristics, erosion
Virginia Institute Scientific Research	2	Thermal
Virginia Polytechnic Institute and Spats University	1	Biology
Virginia State College	5	Algae
Virginia State Water Control Board	5	Water quality

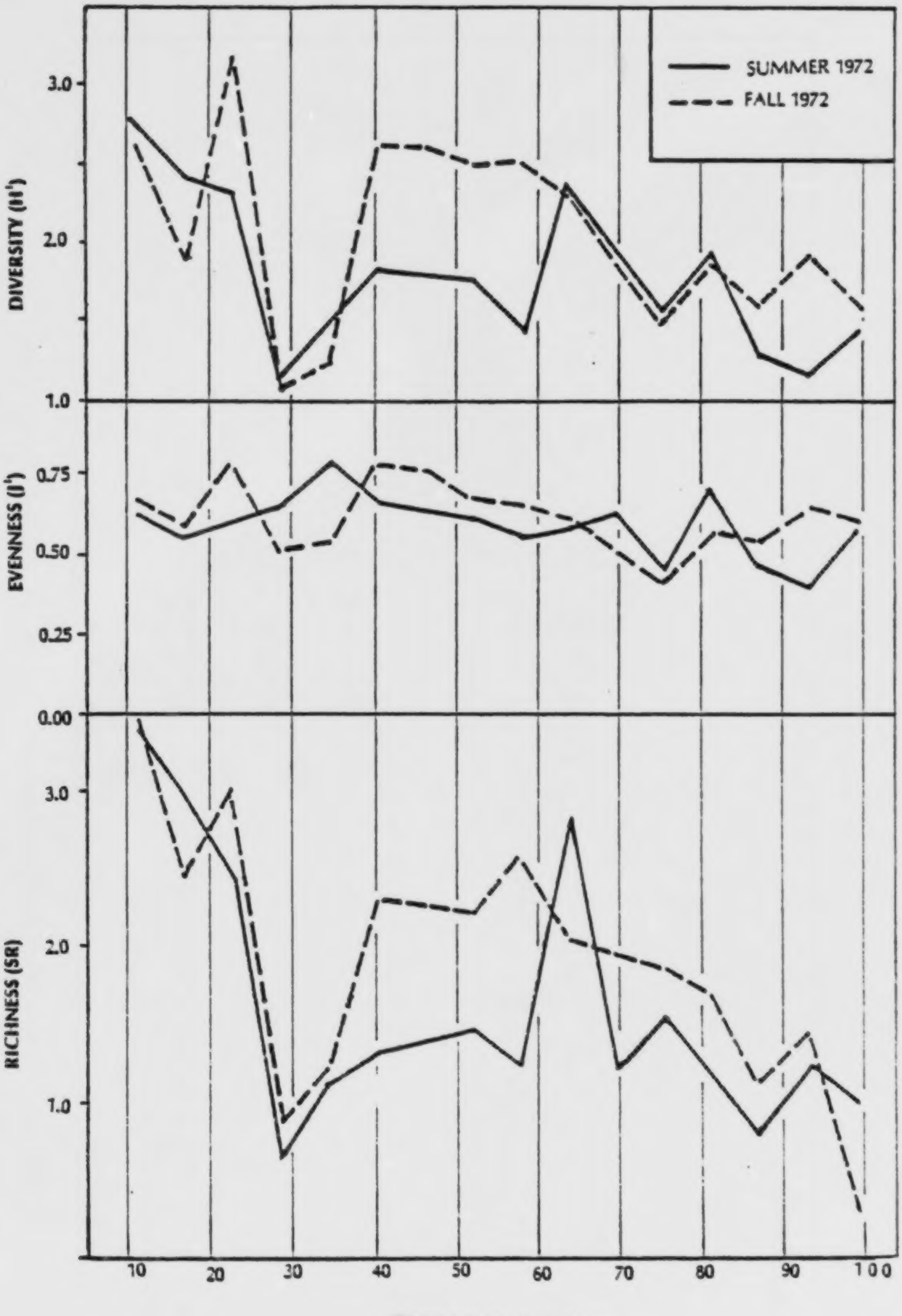

FIGURE VI.6. Species Diversity, Richness and Eveness of the Benthic Invertebrates (Diaz, 1977)

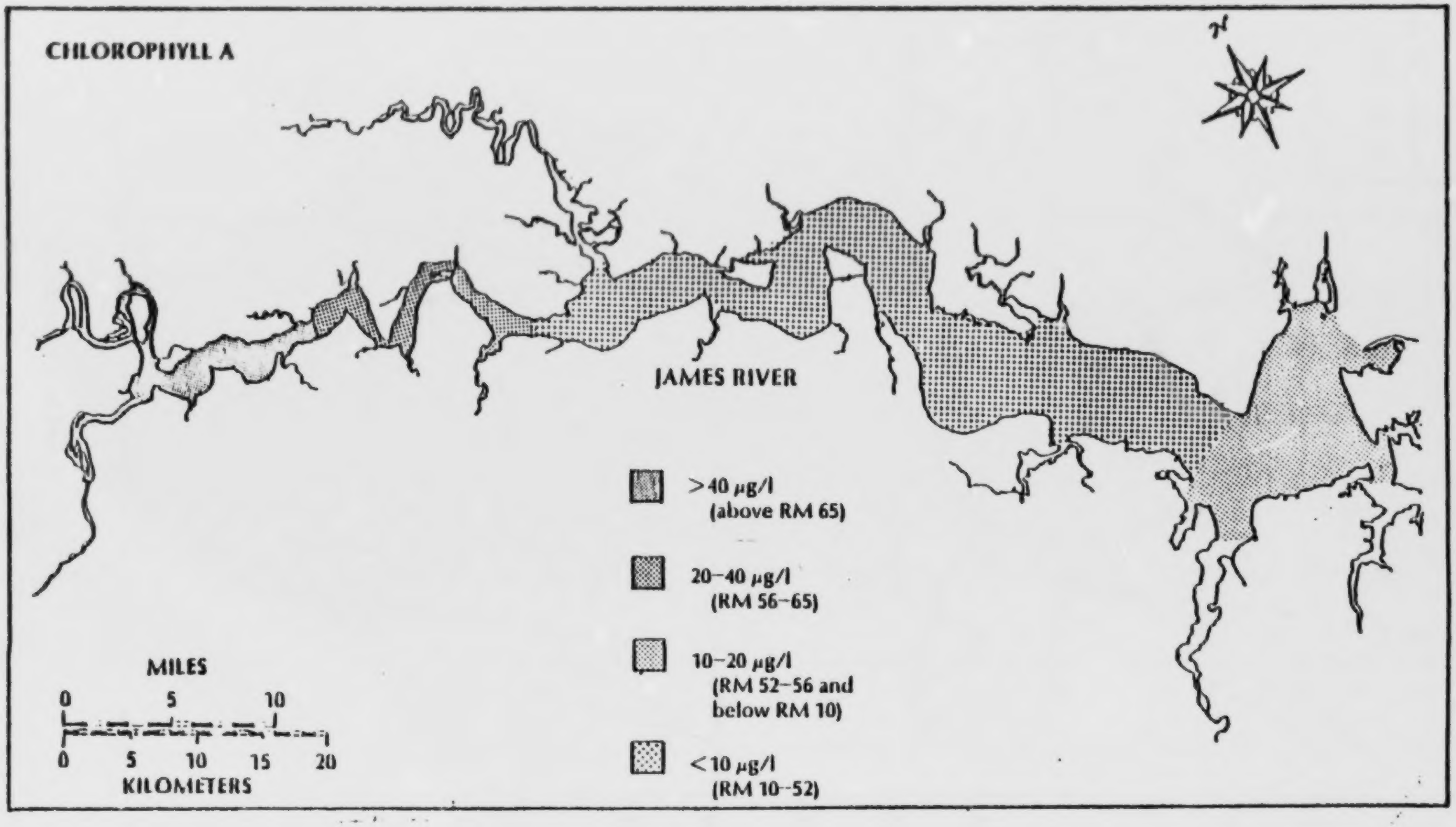
CHLOROPHYLL A
N
JAMES RIVER
▨ >40 μg/l (above RM 65)
▨ 20–40 μg/l (RM 56–65)
▨ 10–20 μg/l (RM 52–56 and below RM 10)
▨ <10 μg/l (RM 10–52)
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE VI.7. Chlorophyll-a Concentrations During the Summer of 1965-1966 (μg/ℓ-ppb)

Due to the flowing river, the fresh-water species probably die as the water becomes more saline. The marine algae decrease as the salinity of the River reaches 1 g/ℓ. Little is known of the algae inhabiting the tidal swamps and marshes (Ott, 1973) or individual phytoplankton species and their contributions to the food web in the Chesapeake Bay in general (Lippson, 1973). Comprehensive lists of biotic organisms are provided in Appendix D.

Lower Tidal Fresh-Water Zone (RM 40-80; Average Salinity 0-0.5 ppth)--

The biota of this area is characterized by the dominance of fresh-water forms with some estuarine species. This area, particularly the upper part, has high organic loadings mainly from the Hopewell area's domestic and industrial wastes. The impacts of organic loadings are reflected in the high coliform bacterial counts (100 - 10,000/100 ml) and oligochaete worms ($>2,000/m^2$). Dense phytoplankton populations and the high chlorophyll-a concentrations in this zone may also be due to the high nutrient levels (VIMS, 1973).

The oligochaete worms, mainly the fresh-water Limnodrilus spp., are the most dominant benthic invertebrate throughout the zone, although the number decreases below the Hopewell area. The chironomid larvae (Coelotanypus scapularis) are also numerous. Since 1972, the introduced Asian clam (Corbicula manilensis) has spread throughout the entire tidal fresh-water zone and has become a dominant species (Diaz, 1977). The brackish water clam (Rangia cuneata) is abundant in the lower section of this zone below RM 65.

Major phytoplankton species are blue-green algae with Anacystis and Gomphosphaeria species predominating at the upper reaches and lower portion of the zone, respectively. Zooplankton densities are found to be highest in this zone between RM 65 and RM 70 (Burbidge, 1974). The dominant zooplankters are limnetic cladocerans and copepods such as Bosmina longirostris, B. coregoni, Diaphanosoma branchyurum, Daphnia parvula, Leptodora kindtti, Cyclops vernalis, and the estuarine species Eurytemora affinis (VIMS, 1973; Hoagman et al., 1973).

This zone serves as major spawning and nursery grounds for anadromous fish, particularly the alosin (herring) group. Dominant fresh-water fish are channel catfish, brown bullhead, and white catfish. Extensive marshes and swamps along the river provide fine habitats for waterfowl and other migratory birds.

Oligohaline Estuary (RM 25-40; Average Salinity 0.5-5 ppth)--

This zone is the transition zone between fresh and salt waters and thus the majority of the area is subject to fresh-water river flow and tidal movement. The average salinity is generally less than 5 ppth and ranges from near zero to 10 ppth. Due to the large fluctuation in salinity, the diversity of nonmobile organisms is lowest in this region, while that of mobile fauna is high by the overlapping of fresh-water and estuarine forms.

Primary productivity in this zone is very low mainly due to high turbidity and thus chlorophyll-a concentrations are the lowest (VIMS, 1973). Diatoms comprise more than 90% of the phytoplankton flora followed by dinoflagellates and green algae (U.S. AEC, 1974). The blue-green algae, the most abundant species in the fresh-water zone, are not found in this area because dissolved solid levels and salinities are high.

Zooplankton populations are sparse with standing crops ranging from 4 to 48 organisms per liter (Vepco, 1973 a,b, 1976). The cohabitants are estuarine copepods (*Acartia tonsa* and *Eurytemora affinis*) along with cladocerans, rotifers, and larvae of barnacles and gastropods (Jorden et al., 1976). The quantity of meroplankton (fish and macro-invertebrate larvae, and fish eggs) is low but constitutes an important part of zooplankton populations in this area. One species of jellyfish is abundant; the sea nettle (*Chrysaora quinquecirrha*) appears in the region up to RM 30 during the summer. (VIMS, 1973).

The most frequently encountered benthic organism in the oligohaline zone is the wedge (marsh) clam (*Rangia cuneata*) (Figures VI.17 and VI.18). *Gammarus daiberi* (an amphipod) and *Scclecolepides viridis* (polychaete) (Figures VI.17 and VI.18) are also dominant through the seasons (Diaz, 1977). Oligochaete worms and dipteran larvae are found in this area when salinity is low (Cain et al., 1972), whereas barnacle larvae enter this area when the salinity is high. The blue crab and small shrimps (Penaeid and palmonid) are also present in the area. At least 37 species of benthic invertebrates represented by 5 phyla are recorded around the Hog Island region of the James River (Vepco, 1973 a,b).

The fish fauna in the oligohaline zone is highly diverse with 49 reported species (White et al., 1972). They include both marine and fresh-water species as well as migrating anadromous fish. This zone serves as a nursery ground for many of the River's fish, particularly Atlantic croaker, hogchoker, bay anchovy, and striped bass. Most dominant inhabitants are hogchoker, white perch, channel and white catfish, bay anchovy, alewife, and spot. The fecal coliform bacteria counts are considered to be lower in this zone (30 - 300 coliforms/100 ml water) than in much of the James River (VIMS, 1973).

Mesohaline Estuary (RM 12-25; Average Salinity 5-15 ppth)--

This zone extends from RM 12 to RM 25 where the salinity ranges between 5 and 15 ppth. Primary productivity of this area is higher than the oligohaline area since turbidity is decreased. Increased productivity may also be ascribed to the nutrient contribution from the salt marshes along the lower James River. The total acreage of the salt marshes in the mesohaline segment alone is approximately one-third of all marshes in the entire James River (VIMS, 1973). The dominant plants of the marshes are three species of cordgrass (*Spartina* spp.) (see Figure VI.28 and Table VI.3). Marine and estuarine diatoms and dinoflagellates are dominant phytoplankters.

The estuarine copepod, Acartia tonsa, appears to be the predominant zooplankter along with many meroplankton larvae. The jellyfish are also important zooplankters in the region; they are comb jelly (Mnemiopsis and Beroe species), sea nettle (Chrysaora), and lion's mane (Cyanea capellata). The jellyfish occur up to RM 20 in the winter.

The most consistent dominants in this zone are three or four species of euryhaline polychaetes, barnacles (Balanus improvisus), and an amphipod (Leptocheirus plumulosus). This zone is known as the most productive oyster bed region in Virginia (Loesch et al., 1975). The soft clam (Mya arenaria) is also abundant, particularly along the shallow shorelines where the oyster seedbeds are distributed. Blue crabs (Callinectes sapidus), the second most commercially important species, are found in their highest density here.

The mesohaline zone is the prime nursery ground for juveniles of many estuarine and marine fish such as hogchoker, bay anchovy, silver perch, spot, croaker, and weakfish.

Polyhaline Estuary (RM 0-20; Average Salinity >15 ppth)--

This zone extends from RM 12 near the James River Bridge to Hampton Roads at the Chesapeake Bay. The area is the largest estuarine section of the James River and is heavily inluenced by activities related to shipping, waste disposal, and land reclamation (Boesch, 1973). Yet due to estuarine circulation processes, the quality of water in this region is not as bad as in the Hopewell area (VIMS, 1973).

The biota of this zone closely resembles the marine species found in Chesapeake Bay or the Atlantic Ocean. Many benthic invertebrates are stenohaline forms which are unable to tolerate wide variation of salinity. Phytoplankton are more dense than in the upper estuary because turbidity is reduced, and high nutrient concentrations are supplied from the Nansemond and Elizabeth Rivers. Chlorophyll-a levels are also higher than in the upper portion of the estuary (Brehmer, 1972; VIMS, 1973).

Neritic diatoms (52 species) and dinoflagellates (19 species) are the major components of the phytoplankton community (Marshall, 1967). A marine diatom, Skeletonema costatum, is by far the most dominant species followed by Asterionella japonica and Nitschia pungens atlantica. The zooplankton populations have not been well documented for this area, although they are expected to be dominated by estuarine species such as Acartia tonsa (VIMS, 1973). This species is the most widely distributed in the Chesapeake Bay and its rivers with maximum density occurring in the areas of 10-20 ppth salinities (Lippson, 1973). Acartia tonsa accounted for more than 50% of the total crustacean zooplankton in the Patuxent River estuary during the warmer months (Heinle, 1966).

The hard clam (Mercenaria mercenaria), which prefers salinities greater than 15 ppth, is very abundant and restricted to this zone only in the James River estuary. Oysters are no longer productive in this area since the introduction of predaceous oyster drills, the parasitic protozoan (Minchinia nelsoni-MSX), and a disease fungus (Labyrinthomyxa marinum) to the area in recent years (VIMS, 1973). These oyster infesting organisms are widely distributed in the polyhaline zone.

Stable salinities and diversified substrates found in the polyhaline estuary support the most diverse benthic communities found in the tidal James River. (Diaz, 1977).

Many commercially important fish utilize this zone as spawning ground (bay anchovy and hogchoker) and as nursery ground (silver perch, weakfish and spot). This area also serves as feeding ground for many marine and anadromous fish such as Atlantic croaker, spot, flounder, bluefish, striped bass, white perch, and herrings.

An estimate of total summer and winter biomass levels for specific fish is presented in Table VI.2. More detailed data on individual species, mapped data on geographic dominance, seasonal dominance and the occurrence of plant, animal, and bird species on the James River can be found in Appendix K.

TABLE VI.2. BIOMASS ESTIMATES DEVELOPED BY VIMS FOR JAMES RIVER FINFISH

Species	Summer Biomass, kg	Winter Biomass, kg
Alewife	NA	22,998
American Eel	910,987	25,814
American Shad	NA	4,632
Atlantic Croaker	25,710,498	136,345
Atlantic Menhaden	119,905	155,722
Atlantic Silverside	NA	42,341
Atlantic Sturgeon	NA	143
Bay Anchovy	19,371,913	27,770
Blackcheek Tonguefish	NA	242
Black Sea Bass	212,843	922
Blueback Herring	59,483	4,275
Bluefish	1,502,179	--
Brown Bullhead	NA	38,443
Carp	16,704,914	29,994
Channel Catfish	10,291,755	330,382
Eastern Silvery Minnow	NA	1,463
Feather Blenny	NA	1,214
Gizzard Shad	NA	5,021
Golden Shiner	NA	2,528
Grey Trout	10,277,312	NA
Hickory Shad	NA	567
Hogchoker	6,206,494	56,532
Naked Goby	NA	98

TABLE VI. 2. (contd)

Species	Summer Biomass, kg	Winter Biomass, kg
Northern Pipefish	NA	416
Northern Searobin	NA	107
Oyster Toadfish	81,738	34,708
Quillback	NA	1,850
River Chub	NA	32
Sea Lamprey	NA	159
Shorthead Redhorse	NA	2,454
Smallmouth Flounder	NA	75
Spot	63,801,871	53,158
Spottail Shiner	NA	15,282
Striped Bass	54,612	397
Striped Blenny	NA	57
Striped Mullet	NA	107
Summer Flounder	7,461,878	35,128
Tadpole Madtom	NA	14
Tantog	NA	3,655
Tassellated Darter	NA	1,035
Threadfin Shad	NA	8,472
White Catfish	3,330,446	32,836
White Crappie	NA	94
White Perch	2,085,012	4,516

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CHAPTER VII - THE MOVEMENT OF KEPONE IN THE JAMES RIVER

SUMMARY

Content

Chapter VII presents the results of the modeling efforts used to predict the movement of Kepone in the James River. The chapter begins with a description of the field sampling program that provided data for calibrating the model. In addition to measured Kepone levels, data include water quality parameters, flow characteristics, and meteorological data. Next, the computer model is briefly described. This is followed by the model output showing predicted movement of Kepone past Burwell Bay under high, average, and low flow conditions. An important aspect of this discussion is the verification of the model using independent data provided by VIMS. Also presented are results of the modeling effort aimed at assessing the efficacy of cleanup efforts applied only to certain segments of the River.

Findings

- Particulate Kepone concentrations up to 0.241 μg/g (ppm) Kepone were found in the River proper. Suspended matter in Bailey Creek contained up to 1.38 μg/g (ppm) Kepone.
- Dissolved Kepone concentrations up to 0.045 μg/ℓ (ppb) were found in the River proper. At most stations, dissolved Kepone was below the detectable limit of 0.006 μg/ℓ (ppb).
- Only two mathematical models are currently available for calculating the migration of contaminants by taking into account both dissolved and particulate species and their interactions.
- Mathematical simulation of Kepone transport under most probable flow conditions yields an estimate of 89.1 kg/yr Kepone transported seaward from Burwell Bay.
- In the most probable scenario, Kepone transport is comprised of 75% dissolved material and 25% associated with particulate material.
- Calibration and verification activities reveal good agreement with all available data.
- Sensitivity analysis under the most probable flow conditions with Kepone bed values twice as high and a 5-fold increase in partition coefficient (5×10^{-4} in place of 1×10^{-4}) yield a prediction of 170 kg/yr transported seaward of Burwell Bay.
- In the latter case, dissolved Kepone accounts for 92% of the total load.
- Analysis of conditions likely to result from implementation of cleanup in selected segments of the River suggests that little or no effect will be noted in total Kepone discharge levels. Ambient Kepone concentrations can be reduced in treated areas, however.

INTRODUCTION

The migration of Kepone in the James River estuary was assessed by both field sampling and mathematical modeling.

THE FIELD SAMPLING PROGRAM

Sorption-desorption kinetics and the affinity of Kepone for organic particles suggest that sediments play a key role in the movement of Kepone in the River. Sediment transport can be modeled to quantify that movement and gain insight into the fate of Kepone residuals. Pursuant to this, a field sampling program was conducted on June 25-28, 1977. The purpose of this program was to obtain data on the James River for input to and calibration of Battelle's sediment and contaminant transport model (FETRA). The overall objective of the modeling effort was to simulate the long-term movement and distribution of Kepone in the 86-km (50-mi) stretch of the James River between Burwell Bay and Hopewell, Virginia. The following describes the sampling program required to calibrate the model, the results of the sampling and analysis, the nature of the model employed, and the model predictions.

The sampling program consisted of data acquisition at eight transects between the James River Bridge and City Point at Hopewell. Three stations were located on each transect and one to three depths were sampled per station for each of three current conditions (flood, slack and ebb). The locations of these stations are listed below and shown in Figure VII.1.

JR-1	James River Bridge
JR-2	Rocklanding Shoal
JR-3	Hog Island
JR-4	West of Swann Point
JR-7	Windmill Point
JR-8	Jordan Point
JR-9	Bailey Bay
JR-10	City Point

[JR-5 and JR-6 were designated for sampling during a complementary effort conducted by personnel at the Virginia Institute of Marine Science.]

JR-1 through 4 were located in the saline portion of the estuary, and JR-7 through 10 were located in the fresh-water portion. JR-8, 9, and 10 were located close together to give a concise view of Kepone near the source area at Hopewell. All cross sections were tidally influenced. Sampling took place during a 20-year low flow period. The dynamic nature of the model takes this into account, however, and verification of output for high flows with previous data on suspended sediments has demonstrated good correlation.

The sampling conducted in the field was directed to: meteorological and hydrological information; channel and flow characteristics; physical and chemical characteristics of suspended load and bed sediments; and water quality characteristics. Kepone analyses were conducted on water, suspended load and bottom sediment samples.

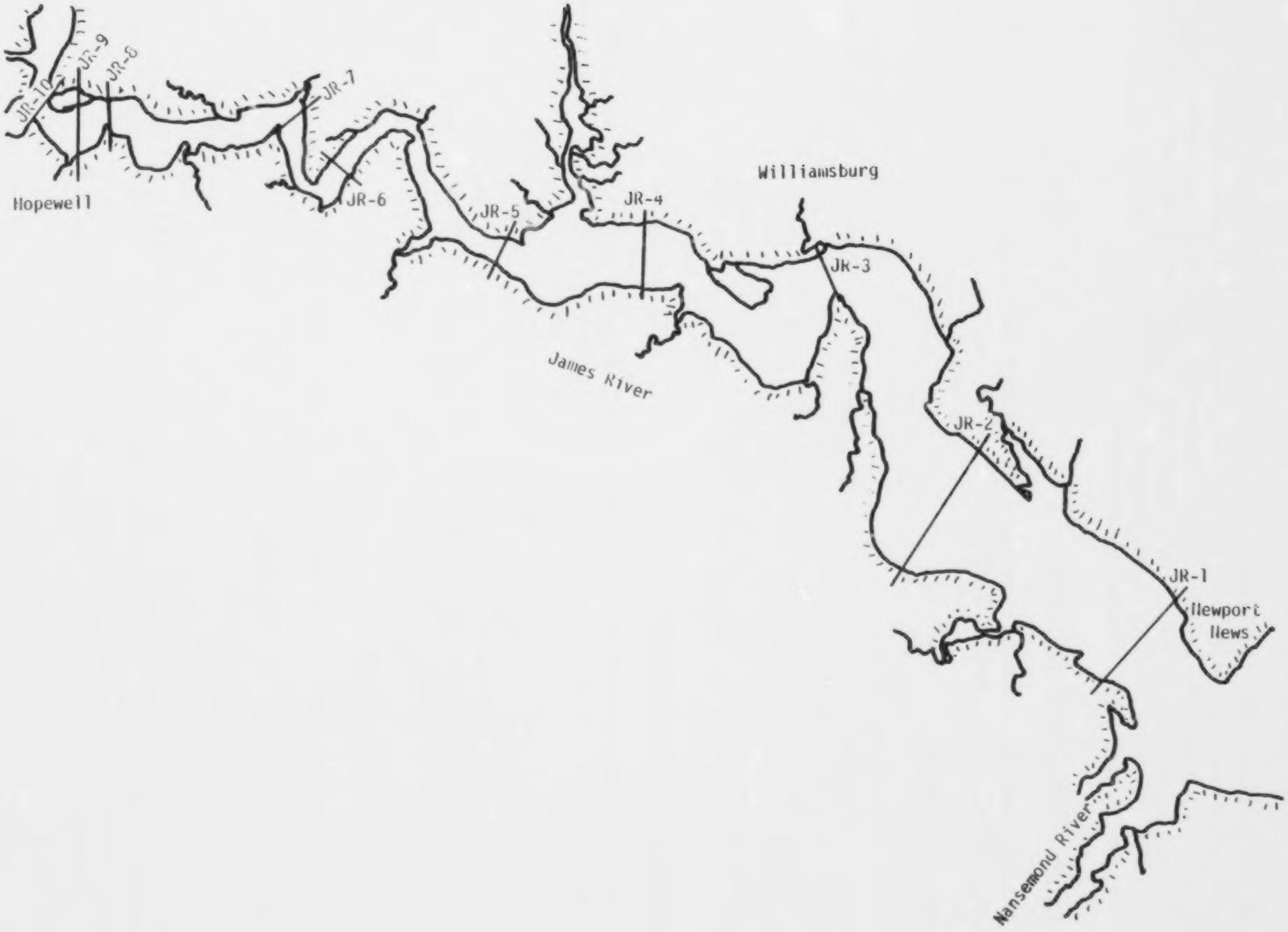

JR-10
JR-9
JR-8
JR-7
JR-6
JR-5
JR-4
JR-3
JR-2
JR-1
Hopewell
Williamsburg
James River
Newport News
Nansemond River

FIGURE VII.1. Location of Transects for James River Sampling

Meteorological and Hydrological Data

Meteorological and hydrological data included wind velocity and direction, and wave height, including period and direction at each station. Wind velocities were measured using a Dwyer hand-held wind meter at cross sections JR-1 through JR-4, and a MFG Climet model 025-9 wind velocity and direction meter at JR-7 through JR-10. Wave height, direction, and period at each station were estimated from visual observations.

Channel and Flow Characteristics

Channel and flow characteristics included a bathymetric profile of each transect, tidal stage measurements, continuous current velocity/direction measurements at the mid-channel station, and current velocity measurements at each sampling depth at each station. Bathymetric profiles were taken at each cross section using a Raytheon DE119 (JR-7 through 10) and DE719 (JR-1 through 4) continuous recording fathometers. Continuous current velocity/direction measurements were recorded using two self-contained, moored Bendix Q-9 Savonius rotor meters and IRC S-235 in situ recorders. Current measurements at the stations were taken using two Hydroproducts model 650-S Savonius rotor current metering systems with analog readout modules. Tidal stage measurements were taken by placing a graduated stake near one of the stations on the cross section, and periodically recording the water level.

Water Quality Characteristics

Water quality parameters measured at each station and depth included water temperature, dissolved oxygen, pH, and conductivity. Temperature measurements were taken with a Yellow Springs Model 51B in situ probe with an analog readout module. Dissolved oxygen measurements were obtained using the modified Winkler titration method. The water samples for the Winkler titration were obtained with 3-ℓ Van Dorn water samplers in series (three depths). Conductivity and pH measurements were performed on-board with a Beckman Model RB3 conductivity bridge and Fisher pH meter.

Suspended and Bed Sediment Characteristics

Two types of suspended sediment data were obtained. A 1-ℓ water sample was obtained from the Van Dorn water samples for each depth for laboratory analysis of suspended sediment load. A continuous 76-ℓ (20-gal) water sample, using a water pump, was obtained at each station under each flow condition at a depth of 1.5 m (5 ft) above the bed. These samples were stored in 19-ℓ (5-gal) containers which were decanted and centrifuged at a later date (2 weeks) and the solids and supernatant water were analyzed in the laboratory for Kepone. Details of the analytical procedure employed can be found in the previous sections on Hopewell studies. Total suspended solids were measured using filtration on 0.45-micron Millipore® filters as prescribed in Standard Methods.

One core sample was taken at each station for particle size analysis and Kepone analysis. Where the water depth permitted, a push tube core sample was taken using a 5.72-cm (2 1/4-in.) push tube sampler with a cellulose acetyl butyrate liner. The sediment samples, while still in the liners, were removed from the push tube barrel and stored for later Kepone analysis and particle size distribution.

RESULTS

A summary of the data collected in the James River sampling program is shown in Tables VII.1 through VII.9. The summary includes cross section and station location, tidal phase and time, water depth of station and depth of sample, current velocity, water temperature, conductivity, pH, dissolved oxygen, suspended solids load, particulate Kepone (attached to suspended sediment), and supernatant Kepone (dissolved). All supernatant Kepone values were derived through petroleum ether:ethyl ether solvent extraction procedures except for those from Bailey Creek which were extracted with a toluene:ethyl acetate solvent. Figures VII.2 through VII.5 are the bathymetric profiles of the eight transects showing the station locations and sampling depths. Figures VII.6 and VII.7 are the vertical distribution of Kepone by sediment size fraction (sand, silt, and clay) for cross sections JR-4, station 3 (West of Swann Point), and JR-9, station 1 (Bailey Bay). Table VII.10 is a composite of Kepone concentration in the upper 12 in. of bed sediments at the remaining cross sections and stations.

DISCUSSION

The James River sampling program was designed to provide information for calibration of the FETRA sediment transport code. One of the major objectives of the program was to observe the longitudinal, lateral, and vertical variations in the measured parameters and to make a qualitative judgment on the importance of the magnitude of these variations during the sampling program. Thus, the field sampling program was confined to a relatively short period of time and the number of cross sections and stations was limited. The following discussion of measured parameters will be in terms of their longitudinal, lateral and vertical variations along the 110 km (70-mi) stretch of the tidal James River, and not necessarily in terms of time variations other than those associated with tidal phase.

TABLE VII.1. RESULTS - JAMES RIVER SAMPLING PROGRAM JR-1 JAMES RIVER BRIDGE June 25, 1977

Station	Tidal Phase	Time	Depth, ft	Current Velocity, ft/sec	Water Temp., °C	Conductivity, µmho	pH	Dissolved Oxygen mg/ℓ	Suspended Solids, mg/ℓ	Suspended Kepone, µg/g	Supernatant Kepone, µg/ℓ
1	Ebb		11.0								
		0835	3.0	1.69		1240	7.3	6.0	42.9		
		0820	8.0	1.35		1250	7.3	5.0	98.6	<0.013	----
	Slack		11.0								
		1110	3.0	1.64		1210	7.4	6.3	40.7		
		1105	8.0	0.90		1210	7.5	6.1	76.4	0.035	----
	Flood		11.5								
		1415	3.0	1.06		1220	7.6	6.1	75.8		
		1410	8.0	0.98		1210	7.6	6.0	87.7	<0.013	<0.006
2	Ebb		27.0								
		0915	3.0	1.50		1250	7.5	6.8	34.9		
		0910	10.0	1.18		1250	7.5	5.9	38.4		
		0905	24.0	1.34		1250	7.4	5.8	44.1	<0.011	----
	Slack		27.5								
		1155	3.0	1.69		1200	7.5	7.1	24.1		
		1150	15.0	1.62		1210	7.5	6.4	26.1		
		1145	24.0	0.37		1270	7.4	5.9	55.6	0.038	----
	Flood		29.0								
		1505	3.0	1.69		1210	7.7	6.7	28.9		
		1500	15.0	1.66		1230	7.6	6.1	40.1		
		1445	26.0	1.08		1220	7.6	6.0	55.6	<0.044	<0.006
3	Ebb		32.0								
		1110	3.0	1.27		1230	7.1	6.2	27.4		
		1005	15.0	1.64		1250	7.3	6.1	33.1		
		1000	29.0	0.88		1260	7.2	5.8	44.6	<0.023	----
	Slack		32.0								
		1245	3.0	0.71		1210	7.5	6.7	23.6		
		1240	15.0	0.20		1220	7.5	5.8	45.8		
		1235	29.0	0.56		1210	7.4	5.7	47.7	0.028	----
	Flood		36.0								
		1545	3.0	1.32		1220	7.7	6.8	18.5		
		1540	15.0	1.28		1230	7.7	5.9	53.8		
		1535	33.0	1.13		1230	7.7	5.9	61.2	<0.012	----

TABLE VII.2. RESULTS - JAMES RIVER SAMPLING PROGRAM JR-2 BURWELL BAY JUNE 26, 1977

Station	Tidal Phase	Time	Depth, ft	Current Velocity, ft/sec	Water Temp., °C	Conductivity, µmho	pH	Dissolved Oxygen mg/ℓ	Suspended Solids, mg/ℓ	Suspended Kepone, µg/g	Supernatant Kepone, µg/ℓ
1	Ebb		15.5								
		0915	3.0	1.50		1200	7.2	6.5	32.3		
		0910	12.0	0.68		1210	7.2	6.0	78.7	<0.012	----
	Slack		13.8								
		1225	3.0	1.30		1180	7.6	6.8	26.1		
		1220	11.0	1.10		1180	7.6	6.8	61.3	0.056	----
	Flood		15.0								
		1515	3.0	1.00		1160	7.5	7.0	17.6		
		1510	12.0	0.68		1180	7.5	6.9	26.7	0.050	----
2	Ebb		34.0								
		1010	3.0	1.69		1200	7.6	6.5	27.0		
		1005	17.0	1.13		1210	7.5	6.0	49.4		
		1000	31.0	0.74		1210	7.5	6.8	24.6	0.143	<0.006
	Slack		34.0								
		1310	3.0	1.69		1180	7.6	6.6	26.8		
		1305	17.0	0.83		1190	7.5	6.2	29.5		
		1300	31.0	0.35		1200	7.5	6.0	55.0	0.026	----
	Flood		29.0								
		1615	3.0	1.69		1160	7.5	6.9	27.8		
		1610	15.0	1.59		1190	7.5	6.2	29.5		
		1605	26.0	1.35		1200	7.4	5.8	45.5	<0.029	----
3	Ebb		13.0								
		1040	3.0	1.28		1200	7.5	6.5	35.1		
		1035	10.0	1.32		1210	7.5	6.1	46.7	<0.027	<0.006
	Slack		11.5								
		1345	3.0	0.39		1140	7.5	6.5	30.4		
		1340	8.0	0.17		1170	7.5	6.5	40.1	<0.050	----
	Flood		13.0								
		1645	3.0	1.69		1160	7.6	7.3	28.7		
		1640	10.0	1.34		1180	7.5	6.6	39.3	<0.030	0.007

TABLE VII.3. RESULTS - JAMES RIVER SAMPLING PROGRAM JR-3 HOG ISLAND JUNE 27, 1977

Station	Tidal Phase	Time	Depth, ft	Current Velocity, ft/sec	Water Temp., °C	Conductivity, μmho	pH	Dissolved Oxygen mg/ℓ	Suspended Solids, mg/ℓ	Suspended Kepone, μg/g	Supernatant Kepone, μg/ℓ
1	Slack		17.0								
		0840	3.0	1.32		1060	7.3	6.2	62.2		
		0835	14.0	1.23		1090	7.2	6.2	87.1	<0.016	----
	Ebb		17.0								
		1120	3.0	1.54		1030	7.3	6.2	76.2		
		1115	14.0	1.39		1050	7.3	6.2	64.8	<0.040	----
	Flood		15.0								
		1610	3.0	1.35		1020	7.4	6.0	36.6		
		1605	12.0	1.47		1040	7.4	5.7	62.8	<0.003	----
2	Slack		31.0								
		0935	3.0	0.90		1000	7.1	6.6	28.1		
		0930	15.0	0.71		1010	7.0	6.4	38.6		
		0925	28.0	0.83		1060	7.2	6.4	37.1	<0.088	0.020
	Ebb		29.0								
		1150	3.0	1.32		1010	7.4	7.0	24.8		
		1140	15.0	1.35		1010	7.4	7.2	22.9		
		1130	26.0	1.25		1020	7.3	7.3	31.9	----	----
	Flood		29.0								
		1645	3.0	0.56		990	7.6	7.5	11.6		
		1640	15.0	0.41		970	7.5	6.8	32.2		
		1635	26.0	0.24		980	7.5	6.8	28.9	<0.078	----
3	Slack		25.0								
		0955	3.0	0.49		1000	7.3	6.9	18.3		
			12.0			1000	7.4	6.7	28.9		
		0950	22.0	0.56		1010	7.3	6.4	31.8	0.076	<0.055
	Ebb		22.0								
		1220	3.0	1.10		990	7.4	6.6	27.4		
			11.0			990	7.4	6.3	24.3		
		1215	19.0	1.13		1040	7.4	6.0	51.2	<0.041	----
	Flood		22.0								
		1715	3.0	0.52		950	7.5	7.5	15.9		
			11.0			960	7.5	7.1	20.8		
		1710	19.0	0.52		950	7.5	6.8	30.5	0.010	<0.054

TABLE VII.4. RESULTS - JAMES RIVER SAMPLING PROGRAM JR-4 WEST OF SWANN POINT JUNE 28, 1977

Station	Tidal Phase	Time	Depth, ft	Current Velocity, ft/sec	Water Temp., °C	Conductivity, µmho	pH	Dissolved Oxygen mg/ℓ	Suspended Solids, mg/ℓ	Suspended Kepone, µg/g	Supernatant Kepone, µg/ℓ
1	Flood		29.0								
		0725	3.0	0.37		630	7.4	6.5	19.5		
		0720	15.0	0.51		670	7.4	6.9	25.6		
		0715	26.0	0.86		740	7.4	6.9	23.7	0.098	----
	Slack		31.0								
		1050	3.0	1.49		860	7.3	7.0	18.9		
		1045	15.0	1.40		860	7.3	6.5	30.2		
		1040	28.0	1.17		890	7.3	6.5	61.2	0.057	----
	Ebb		26.0								
		1325	3.0	1.62		790	7.4	7.4	20.1		
		1320	13.0	1.35		830	7.4	6.7	21.8		
		1315	23.0	0.73		860	7.3	6.6	28.2	0.088	<0.006
2	Flood		13.0								
		0800	3.0	1.42		650	7.4	6.5	22.9		
		0755	10.0	1.08		660	7.3	6.4	32.2	0.239	----
	Slack		12.0								
		1110	3.0	0.73		860	7.3	6.7	19.1		
		1105	9.0	0.69		850	7.3	6.5	33.8	0.068	<0.006
	Ebb		12.0								
		1340	3.0	1.69		770	7.3	7.1	21.3		
		1335	9.0	1.15		790	7.3	6.9	24.2	0.175	<0.006
3	Flood		14.0								
		0835	3.0	1.25		670	7.3	6.7	32.9		
		0830	11.0	1.25		720	7.3	6.7	54.4	0.107	<0.006
	Slack		12.0								
		1210	3.0	0.70		790	7.4	7.6	13.6		
		1205	9.0	0.44		810	7.4	6.6	21.6	0.148	----
	Ebb		11.0								
		1405	3.0	1.69		690	7.4	7.9	16.5		
		1400	8.0	1.30		700	7.4	7.1	32.1	0.060	<0.006

TABLE VII.5. RESULTS - JAMES RIVER SAMPLING PROGRAM JR-7 WINDMILL POINT JUNE 28, 1977

Station	Tidal Phase	Time	Depth, ft	Current Velocity, ft/sec	Water Temp., °C	Conductivity, µmho	pH	Dissolved Oxygen mg/ℓ	Suspended Solids, mg/ℓ	Suspended Kepone, µg/g	Supernatant Kepone, µg/ℓ
1	Flood		13.0								
		0900	3.0	1.62	27.5	260	6.9	3.8	35.1		
			6.5	1.44	27.0	260	7.0	3.7	41.2		
			10.0	1.44	27.0	260	7.0	3.7	31.5	0.140	----
	Slack		15.0								
		1230	13.0	0.85	27.5	250	7.1	4.8	10.4		
			8.0	0.68	28.0	255	7.1	4.4	24.4		
			12.0	0.85	28.0	260	7.1	4.4	27.1	0.122	----
	Ebb		12.5								
		1600	3.0	1.27	28.0	245	7.0	5.1	27.4		
			6.5	1.44	28.0	250	6.9	4.9	28.4		
			8.0	1.52	28.0	250	6.6	4.6	54.9	0.135	----
2	Flood		27.0								
		0925	3.0	1.27	27.5	260	7.0	4.0	11.1		
			13.5	1.01	27.5	260	7.1	3.7	15.9		
			23.0	0.93	27.5	260	7.1	3.7	20.2	0.119	----
	Slack		24.0								
		1255	3.0	0.51	28.0	250	7.0	4.5	16.4		
			11.0	0.59	28.0	260	7.1	4.4	17.0		
			20.0	0.17	28.0	260	7.1	4.3	22.0	0.104	----
	Ebb		25.0								
		1620	3.0	1.54	28.5	250	6.8	4.9	23.1		
			12.0	1.35	28.0	250	6.8	4.8	22.6		
			21.0	1.06	28.0	250	6.6	4.9	33.2	0.084	----
3	Flood		4.0								
		0945	1.0	0.48	27.5	250	7.0	4.4	17.2	0.241	----
	Slack		4.5								
		1320	1.0	0.08	30.0	240	7.0	5.2	32.0	0.133	<0.006
	Ebb		4.0								
		1630	1.0	0.51	28.5	260	6.5	6.1	29.9	0.126	----

TABLE VII.6. RESULTS - JAMES RIVER SAMPLING PROGRAM JR-8 JORDAN POINT JUNE 27, 1977

Station	Tidal Phase	Time	Depth, ft	Current Velocity, ft/sec	Water Temp., °C	Conductivity, μmho	pH	Dissolved Oxygen mg/ℓ	Suspended Solids, mg/ℓ	Suspended Kepone, μg/g	Supernatant Kepone, μg/ℓ
1	Flood		14.0								
		0830	2.0	1.35	27.5	340	7.0	0.3	37.8		
			6.0	1.44	28.5	340	7.0	0.3	35.5		
			10.0	1.52	28.5	320	7.1	0.5	53.6	----	0.006
	Slack		11.0								
		1200	2.5	0.25	29.0	310	7.2	1.1	24.4		
			5.0	0.08	29.0	290	7.3	2.3	----		
			8.0	0.17	29.0	300	7.4	2.8	36.7	----	----
	Ebb		9.0								
		1525	3.0	1.52	30.0	280	6.9	4.3	70.7		
			4.5	1.44	30.0	270	6.9	4.7	73.3		
			6.0	1.44	30.0	260	6.9	5.0	70.1	0.020	----
2	Flood		26.0								
		0905	3.0	1.35	27.5	255	7.1	3.6	27.8		
			13.0	1.35	28.0	255	7.1	3.6	27.8		
			23.0	1.32	28.0	258	7.3	3.6	23.0	0.154	----
	Slack		28.0								
		1222	3.0	0.68	28.0	260	7.4	3.7	19.0		
			14.0	0.59	29.0	245	7.0	3.5	25.2		
			24.0	0.68	28.5	240	7.0	3.3	24.9	0.114	----
	Ebb		29.0								
		1553	3.0	1.01	29.0	260	7.1	7.4	27.0		
			14.5	1.61	28.0	060	7.1	4.7	29.1		
			26.0	1.52	28.5	260	7.2	3.0	58.5	0.120	----
3	Flood		5.0								
		0930	2.0	0.73	27.0	260	6.8	5.3	47.8	0.053	----
	Slack		4.0								
		1240	2.0	0.25	31.5	230	7.1	6.4	----	----	----
	Ebb		4.0								
		1615	2.0	0.42	31.0	240	8.2	9.2	32.0	----	----

TABLE VII.7. RESULTS - JAMES RIVER SAMPLING PROGRAM JR-9 BAILEY BAY JUNE 26, 1977

Station	Tidal Phase	Time	Depth, ft	Current Velocity, ft/sec	Water Temp., °C	Conductivity, μmho	pH	Dissolved Oxygen mg/ℓ	Suspended Solids, mg/ℓ	Suspended Kepone, μg/g	Supernatant Kepone, μg/ℓ
1	Flood		3.0								
		0740	1.5	0.34	26.0	260	7.0	4.3	57.5	0.117	----
	Slack		3.0								
		1134	1.5	0.34	29.0	190	7.3	4.3	18.9	0.124	----
	Ebb		3.0								
		1406	1.5	0.59	29.0	260	7.4	5.1	29.9	0.074	0.016
2	Flood		27.0								
		0655	3.0	0.17	24.0	235	7.1	5.3	23.8		
			14.0	0.08	24.0	235	7.1	5.3	23.8		
			25.0	0.25	24.0	240	6.9	5.2	25.6	0.021	----
	Slack		28.0								
		1055	3.0	1.10	27.0	230	7.4	3.5	22.1		
			11.0	0.85	27.0	230	7.4	3.9	28.9		
			22.0	0.68	27.0	230	7.4	3.0	27.8	0.029	----
	Ebb		27.0								
		1348	3.0	2.20	29.0	265	7.1	3.2	22.1		
			11.0	2.11	27.5	260	7.2	3.5	25.3		
			22.0	1.69	28.0	260	7.3	4.2	35.1	<0.081	----
3	Flood		3.0								
		0804	1.5	0.68	27.0	240	7.3	6.0	46.6	0.075	----
	Slack		3.0								
		1156	1.5	0.68	30.0	230	7.6	7.6	40.2	0.078	----
	Ebb		3.0								
		1420	1.5	0.85	29.0	225	7.3	8.5	33.4	<0.392	----

TABLE VII.8. RESULTS - JAMES RIVER SAMPLING PROGRAM JR-10 CITY POINT
JUNE 25, 1977

Station	Tidal Phase	Time	Depth, ft	Current Velocity, ft/sec	Water Temp., °C	Conductivity, μmho	pH	Dissolved Oxygen mg/ℓ	Suspended Solids, mg/ℓ	Suspended Kepone, μg/g	Supernatant Kepone, μg/ℓ
1	Flood		42.0								
		0615	3.0	1.52	22.0	225	8.4	5.7	30.9		
			20.0	1.27	22.5	225	8.3	5.3	26.0		
			38.0	1.10	22.0	230	8.2	5.9	34.9	0.028	----
	Slack		42.0								
		0934	3.0	1.18	28.0	260	8.2	3.4	28.0		
			20.0	1.12	27.0	250	8.1	3.3	29.1		
			37.0	0.91	27.0	260	7.9	3.4	26.6	0.134	----
	Ebb		42.0								
		1230	3.0	1.35	25.5	240	7.7	5.0	28.9		
			20.0	1.61	26.0	240	7.7	3.4	19.9		
			37.0	1.18	26.3	260	7.7	3.5	39.4	0.019	----
2	Flood		4.5								
		0705	2.5	0.14	23.5	230	8.6	5.5	45.6	0.058	----
	Slack		5.0								
		1018	3.0	0.14	28.2	235	7.3	6.5	32.5	<0.018	----
	Ebb		4.0								
		1305	2.0	1.18	----	230	7.7	5.6	47.8	0.044	----
3	Flood		6.0								
		0730	3.0	----	23.5	235	9.0	5.9	40.0	0.063	----
	Slack		6.0								
		1030	3.0	----	30.0	240	7.7	6.3	20.3	0.069	----
	Ebb		6.0								
		1335	3.0	----	----	230	7.6	5.9	23.5	0.094	0.042

TABLE VII.9. RESULTS - JAMES RIVER SAMPLING PROGRAM BAILEY CREEK JUNE 27, 1977

Station	Tidal Phase	Time	Depth, ft	Current Velocity, ft/sec	Water Temp., °C	Conductivity, μmho	pH	Dissolved Oxygen mg/ℓ	Suspended Solids, mg/ℓ	Suspended Kepone, μg/g	Supernatant Kepone, μg/ℓ
	Flood	1000	1.0	0.39	33.0	1500	8.2	0.0	30.8	0.46	0.031
	Slack	1310	1.5	0.42	35.5	1250	7.9	0.0	48.4	0.077	0.053
	Ebb	1655	2.5	0.81	32.0	1500	11.0	0.0	62.7	1.38	0.24

TABLE VII.10. KEPONE IN BED SEDIMENTS

Cross-Section	Station	Composite Depth (in.)	Kepone (μg/g) (ppm)
JR-1	1	0-12	<0.002
JR-1	2	0-12	0.003
JR-1	3	0-12	<0.002
JR-2	1	0-12	<0.002
JR-2	2	0-12	<0.005
JR-2	3	0-4	<0.001
JR-3	1	0-12	<0.001
JR-3	3	0-5	<0.003
JR-4	1	0-10	<0.002
JR-4	2	0-12	<0.002
JR-4	3	0-12	<0.002
JR-7	1	0-12	0.044
JR-7	2	0-1	0.170
JR-7	3	0-12	0.032
JR-8	1	0-12	0.422
JR-8	2	0-12	<0.001
JR-8	3	0-12	0.005
JR-9	1	0-6	0.009
JR-9	3	0-12	<0.003
JR-10	1	0-12	0.006
JR-10	2	0-12	<0.003
JR-10	3	0-12	<0.003

Bathymetry

The tidal James River averages about 6.29 km (4 mi) wide in the more saline portion and 1.6 km (1 mi) or less in the upper fresh-water tidal portion. As can be seen in Figures VII.2 through VII.5 not only do the widths vary substantially along the 110 km (70 mi) reach, but the lateral depth variations are also large. In the lateral dimensions, the River can be divided into the main flow channel 6.1 m (20 ft) or greater in depth, channel margins 3 to 6 m (10 to 20 ft) in depth and subtidal flats less than 3 m (less than 10 ft) in depth. In the lower or saline portion of the tidal James River the subtidal flats encompass up to 90% of the bottom surface area. In the upper or nonsaline portion of the tidal James River, the subtidal flats seldom account for over 50% of the bottom surface area.

Flow Characteristics

Flow characteristics in the tidal James River are primarily a function of tidal currents, fresh-water discharge and wind-generated currents. During the June 25-28 sampling program the fresh-water discharge was very low and the wind velocity seldom exceeded 5 knots. Therefore, during this time period tidal generated currents were the principal currents.

Mid-channel current velocities differed only slightly from transect to transect, varying up to slightly over 1 knot at maximum flood and ebb flow. The largest variations occurred in the lateral and vertical dimensions. Generally, current velocities decreased with depth and were greatest in the deep water flow channel, decreasing towards the tidal flats. Figures VII.8 through VII.15 are comparisons of the predicted currents, continuous current records and depth-averaged instantaneous current velocity measurements. During the sampling program on June 25-28, the flood currents were generally of greater magnitude and of longer duration than the predicted current, whereas the ebb currents were of lesser magnitude and of shorter duration than the predicted current. This deviation from the predicted current is more than likely due to the extremely low fresh-water discharge during the sampling program.

Temperature

The water temperature during the June 25-28 sampling program ranged from 26.8 to 32°C. Water temperatures in Bailey Creek generally exceeded those in the James, ranging from 32 to 35.5°C. Water temperatures closely followed the daily temperature pattern with the lowest temperatures in the morning and the highest in the late afternoon. Slight vertical gradients of approximately 1°C were observed in the deeper areas. The shallow subtidal flats tended to have a greater range in water temperatures than did the deeper areas of the river.

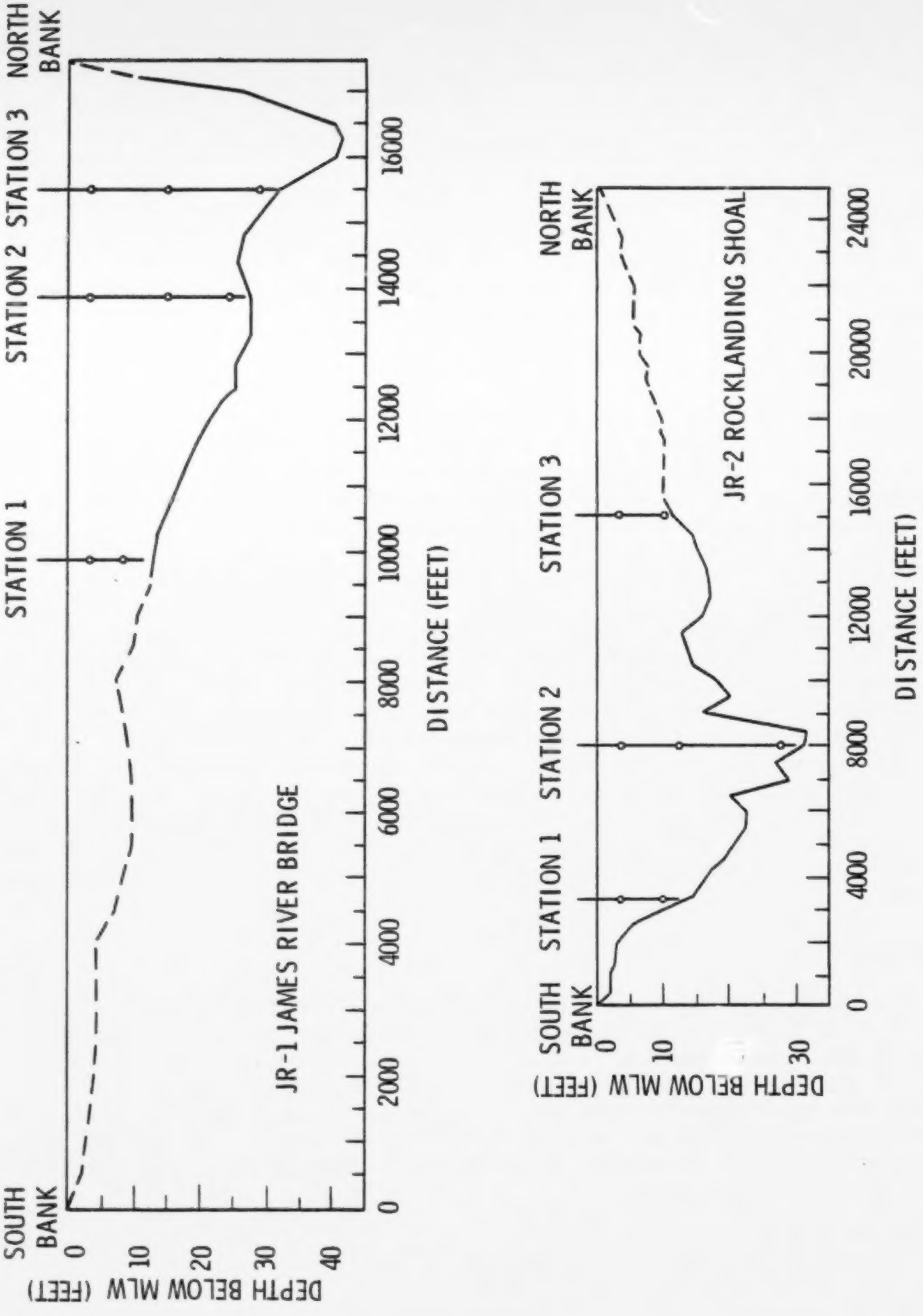


FIGURE VII.2. Bathymetry at JR-1 and JR-2

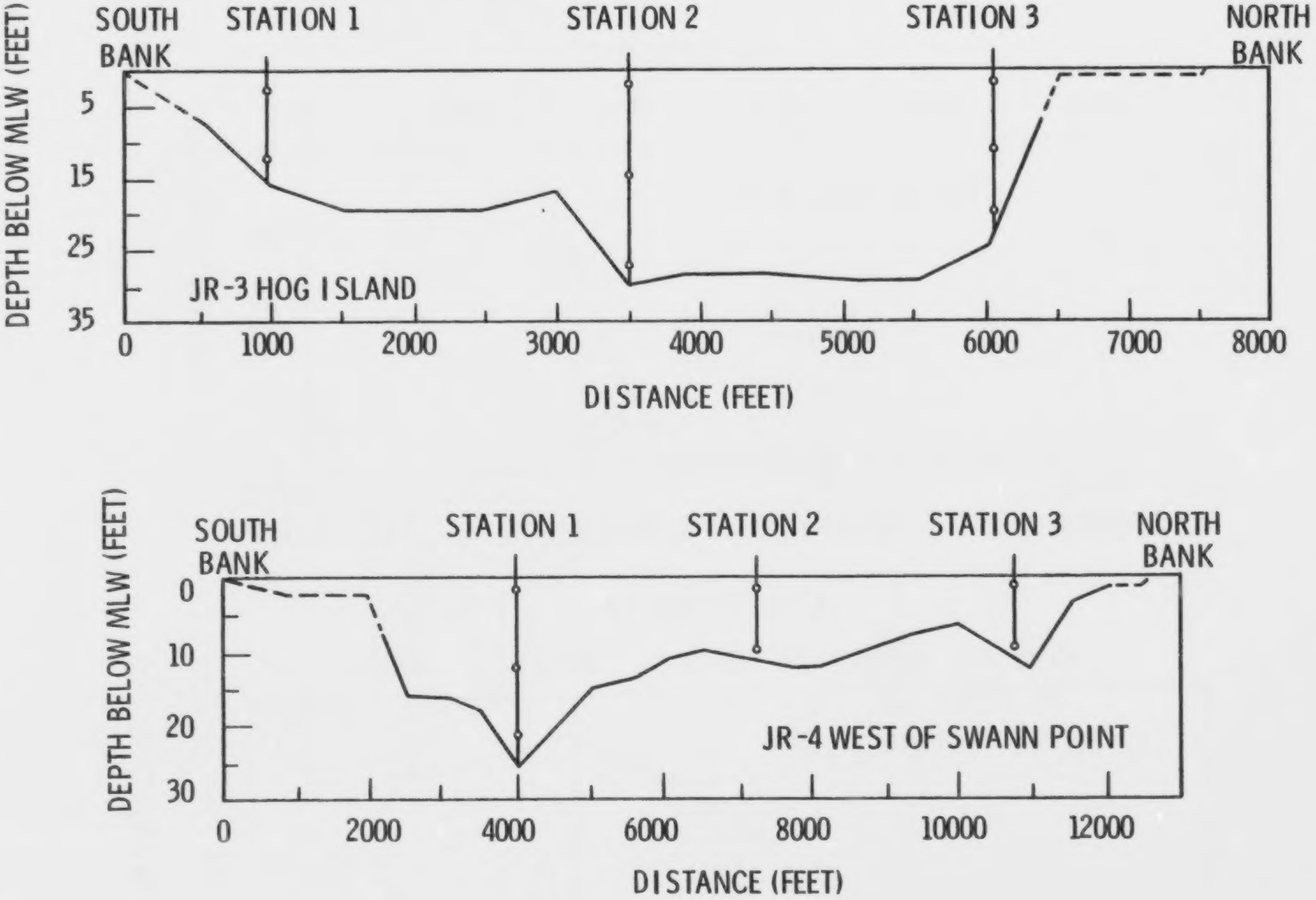


FIGURE VII.3. Bathymetry at JR-3 and JR-4

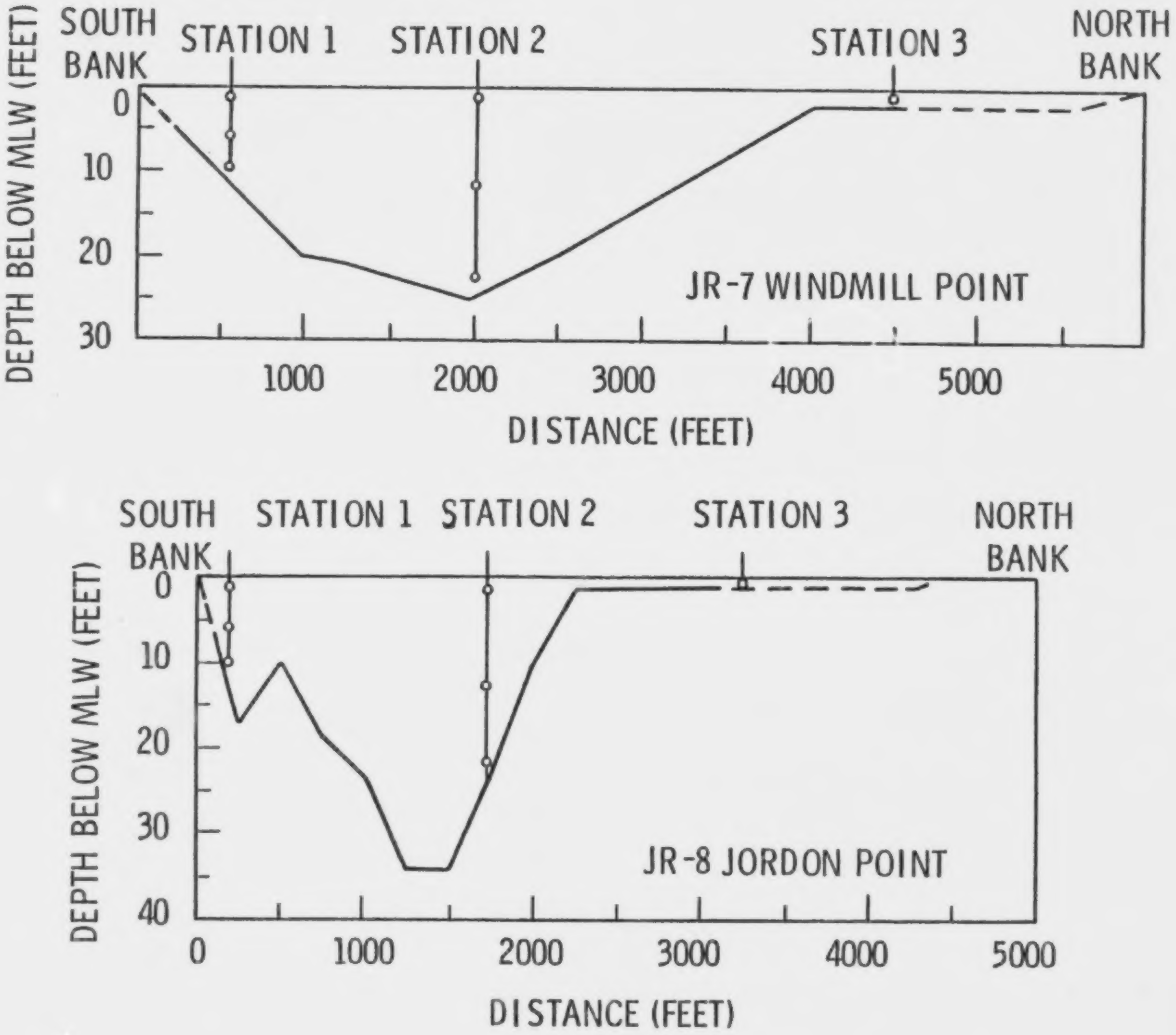


FIGURE VII.4. Bathymetry at JR-7 and JR-8

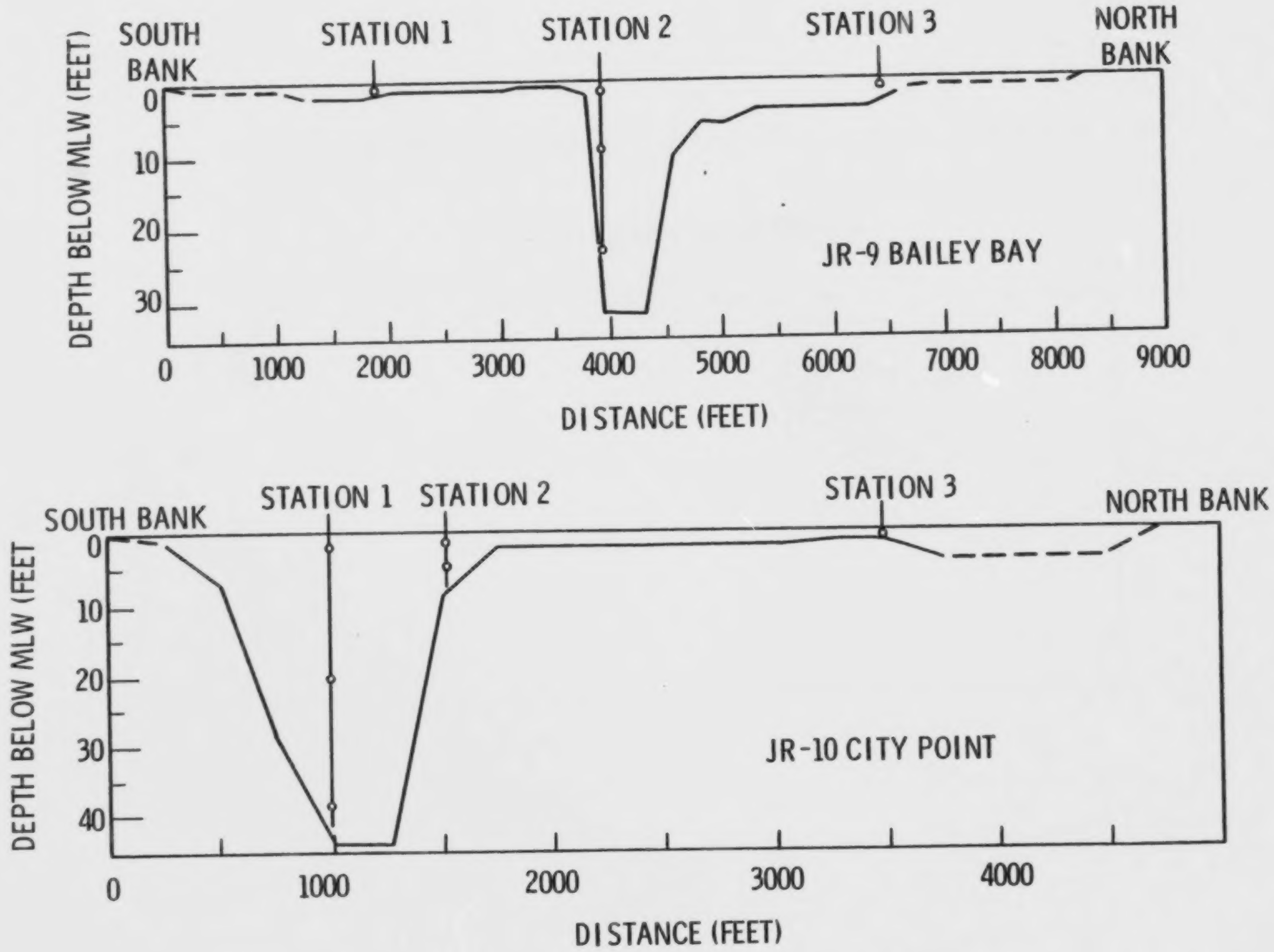


FIGURE VII.5. Bathymetry at JR-9 and JR-10

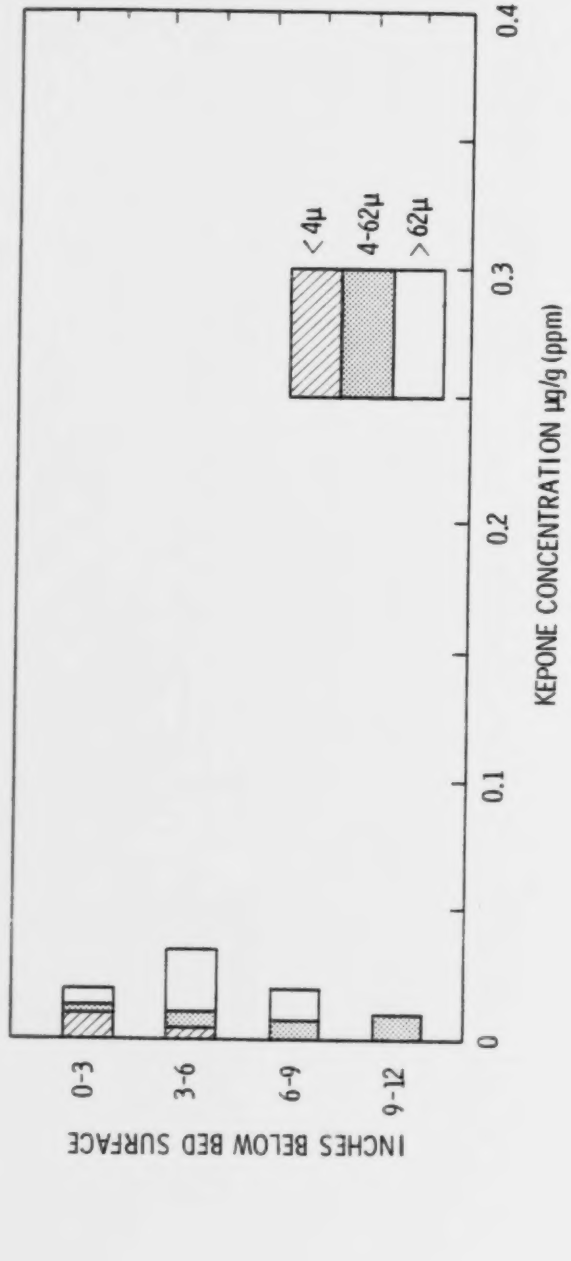


FIGURE VII.6. Depth Distribution of Kepone by Sediment Size Fraction - JR-9 Bailey Bay

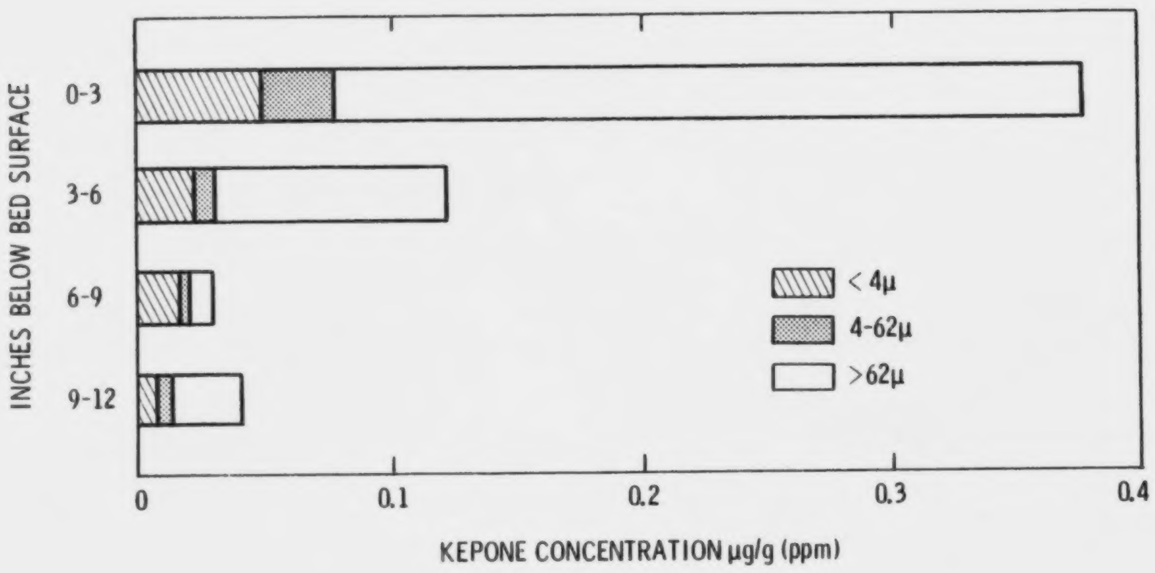


FIGURE VII.7. Depth Distribution of Kepone by Sediment Size Fraction - JR-4 West of Swann Point

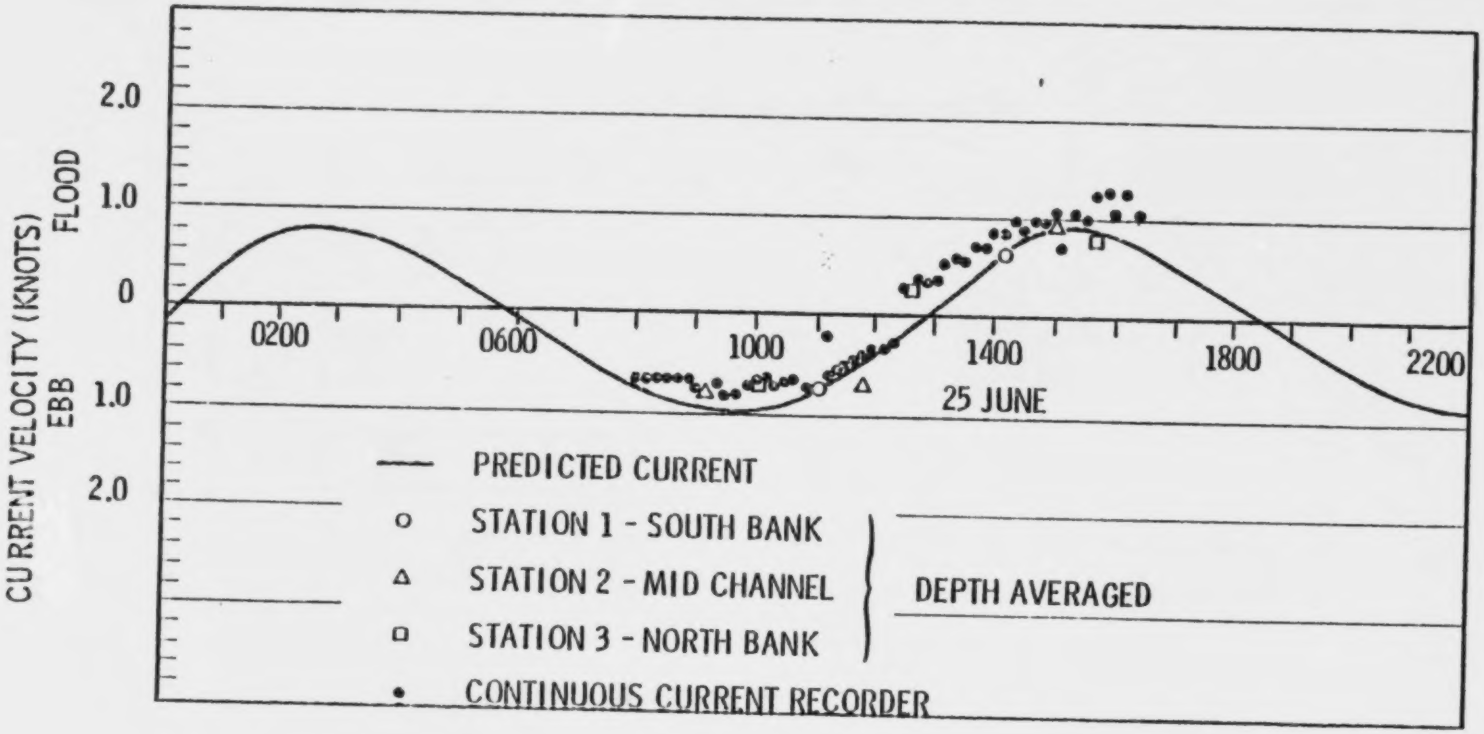


FIGURE VII.8. JR-1 James River Bridge

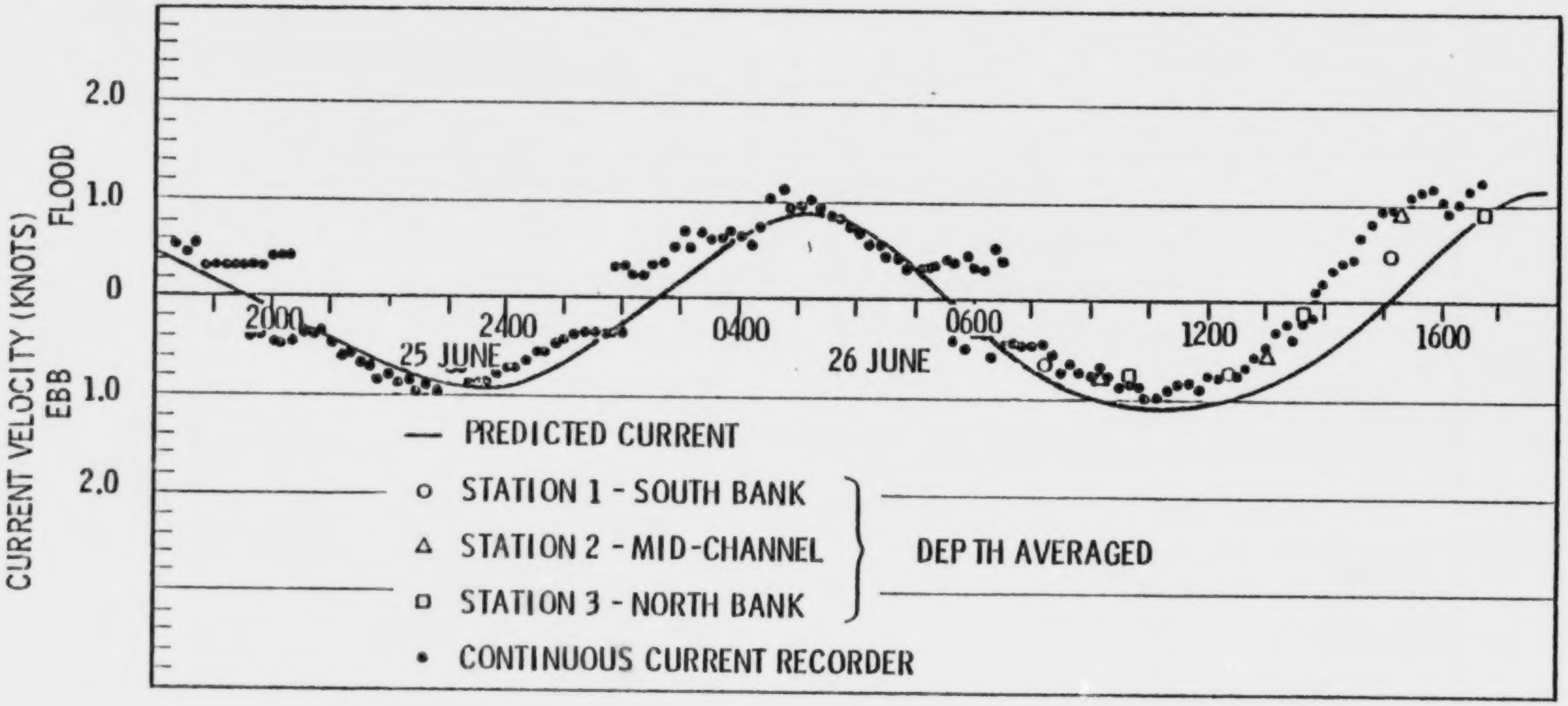


FIGURE VII.9. JR-2 Rocklanding Shoal

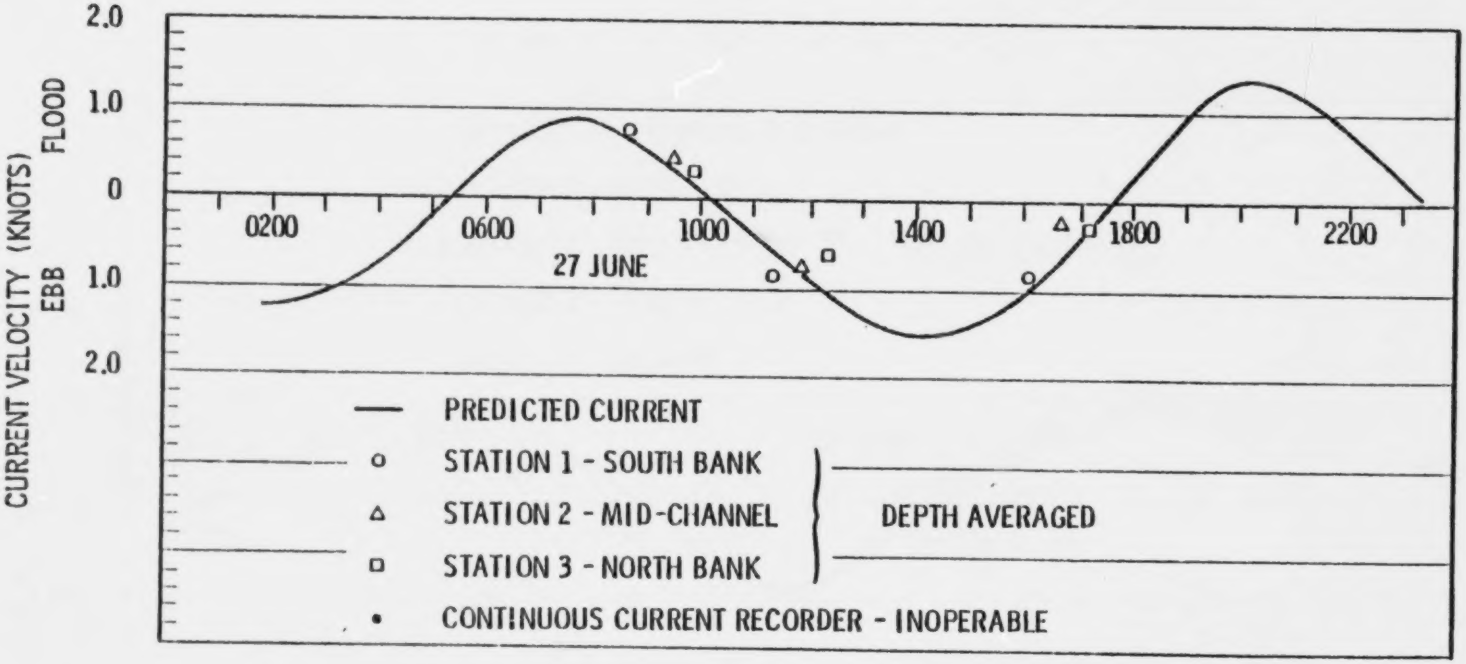


FIGURE VII.10. JR-3 Hog Island

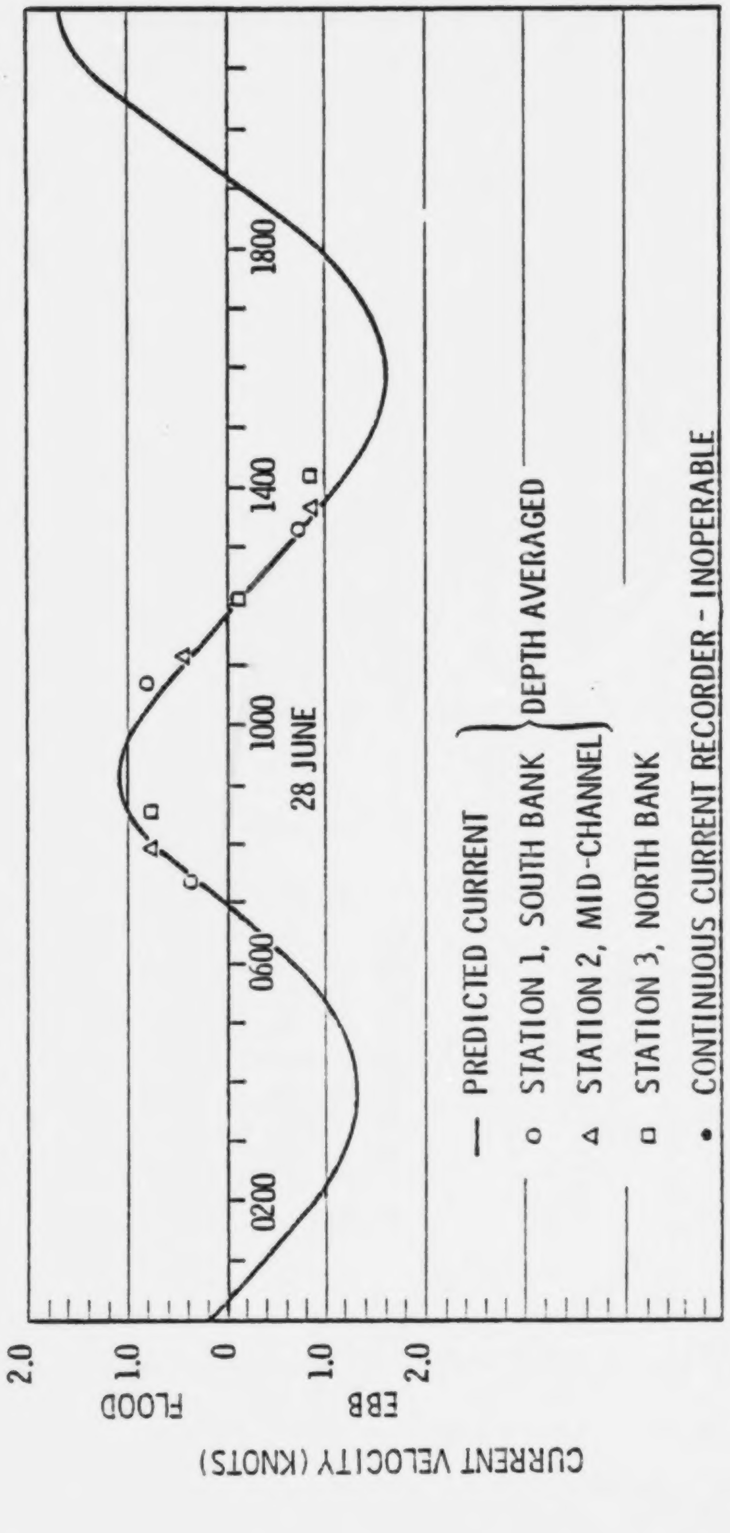


FIGURE VII.11 JR-4 West of Swann Point

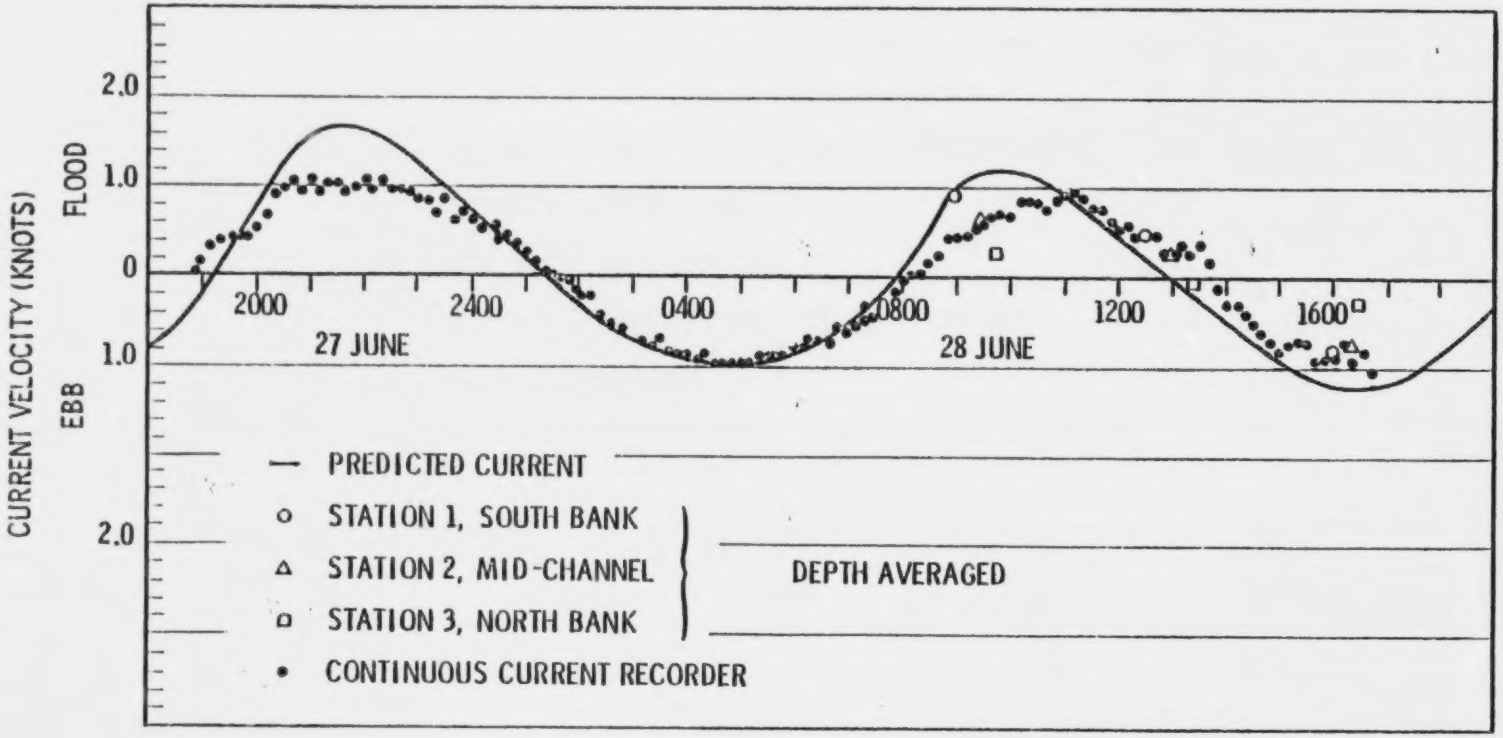


FIGURE VII.12. JR-7 Windmill Point

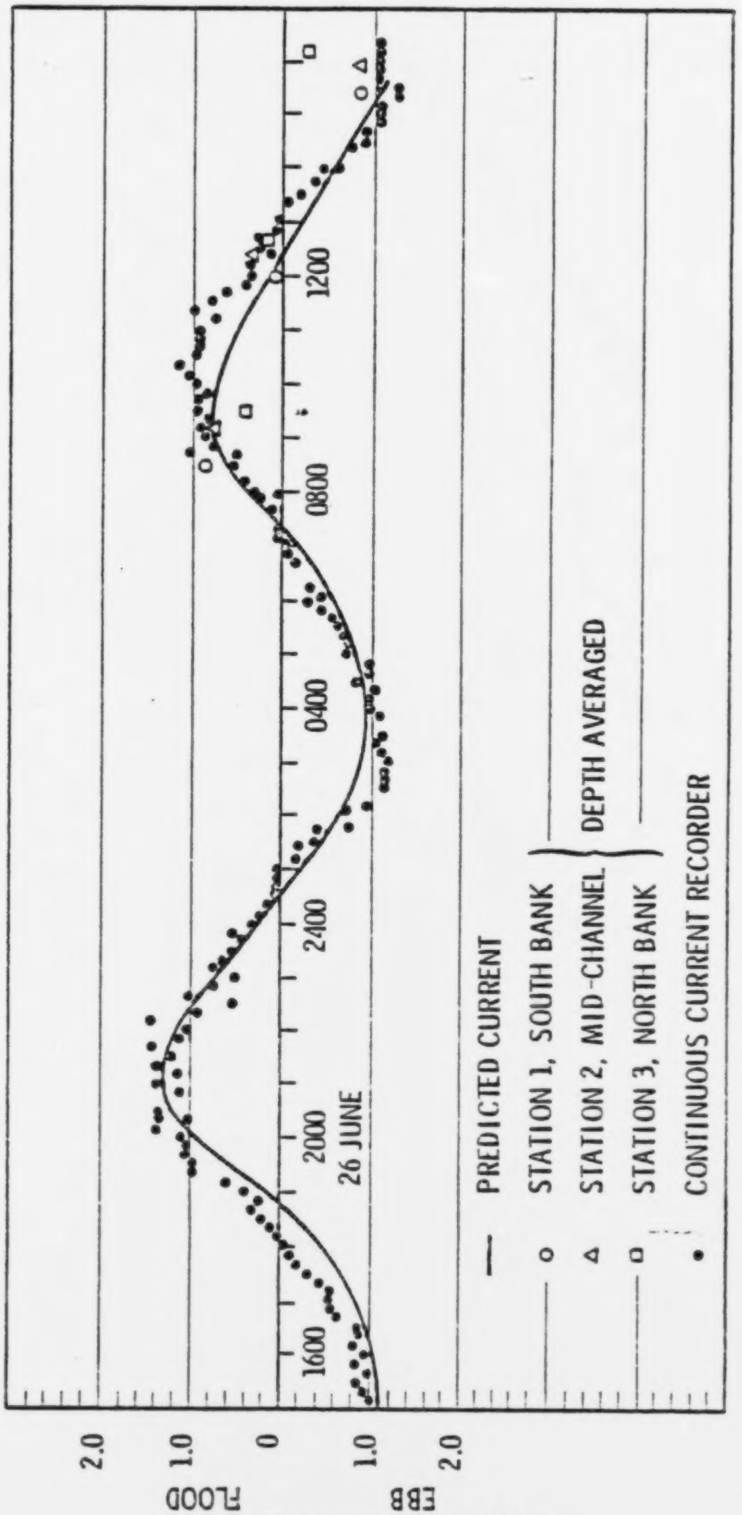


FIGURE VII.13. JR-8 Jordan Point

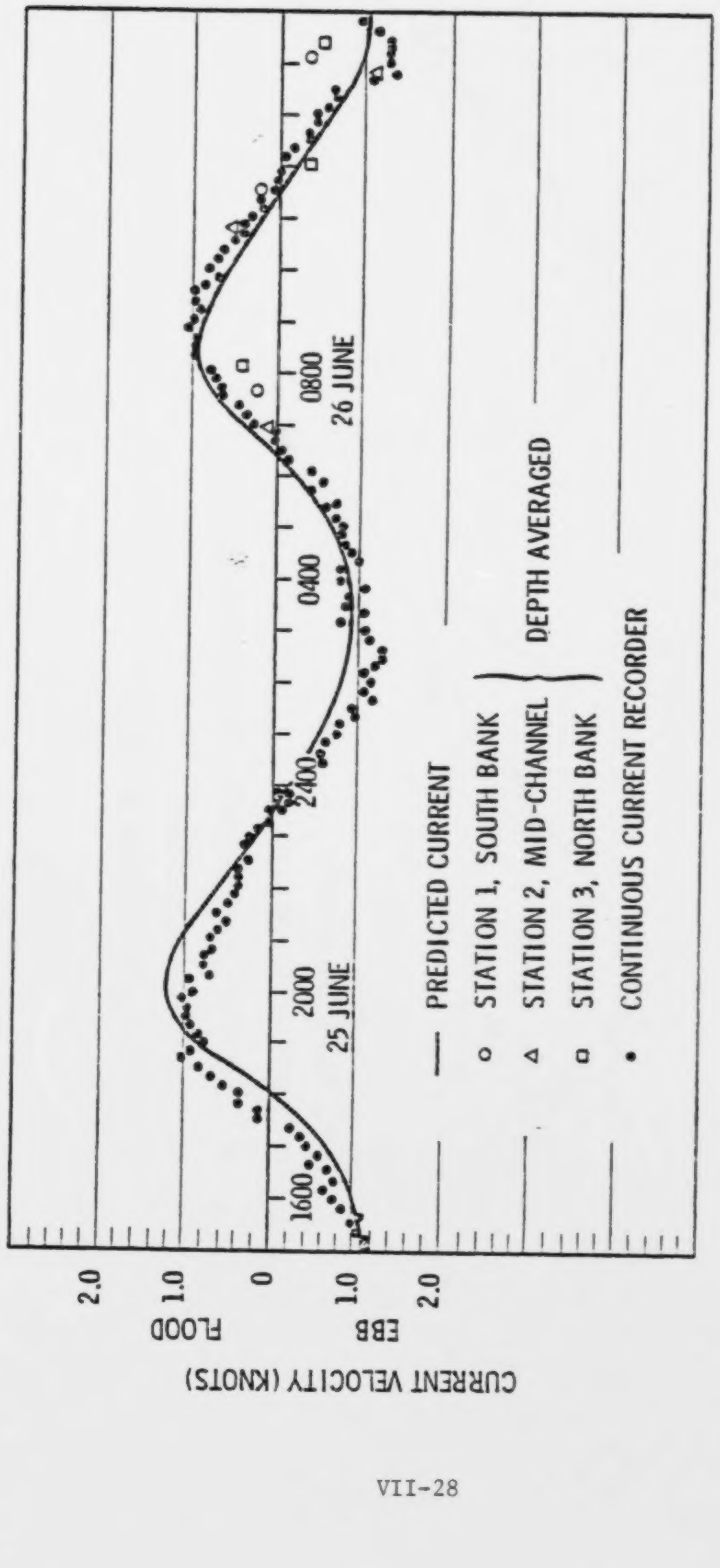


FIGURE VII.14. JR-9 Bailey Bay

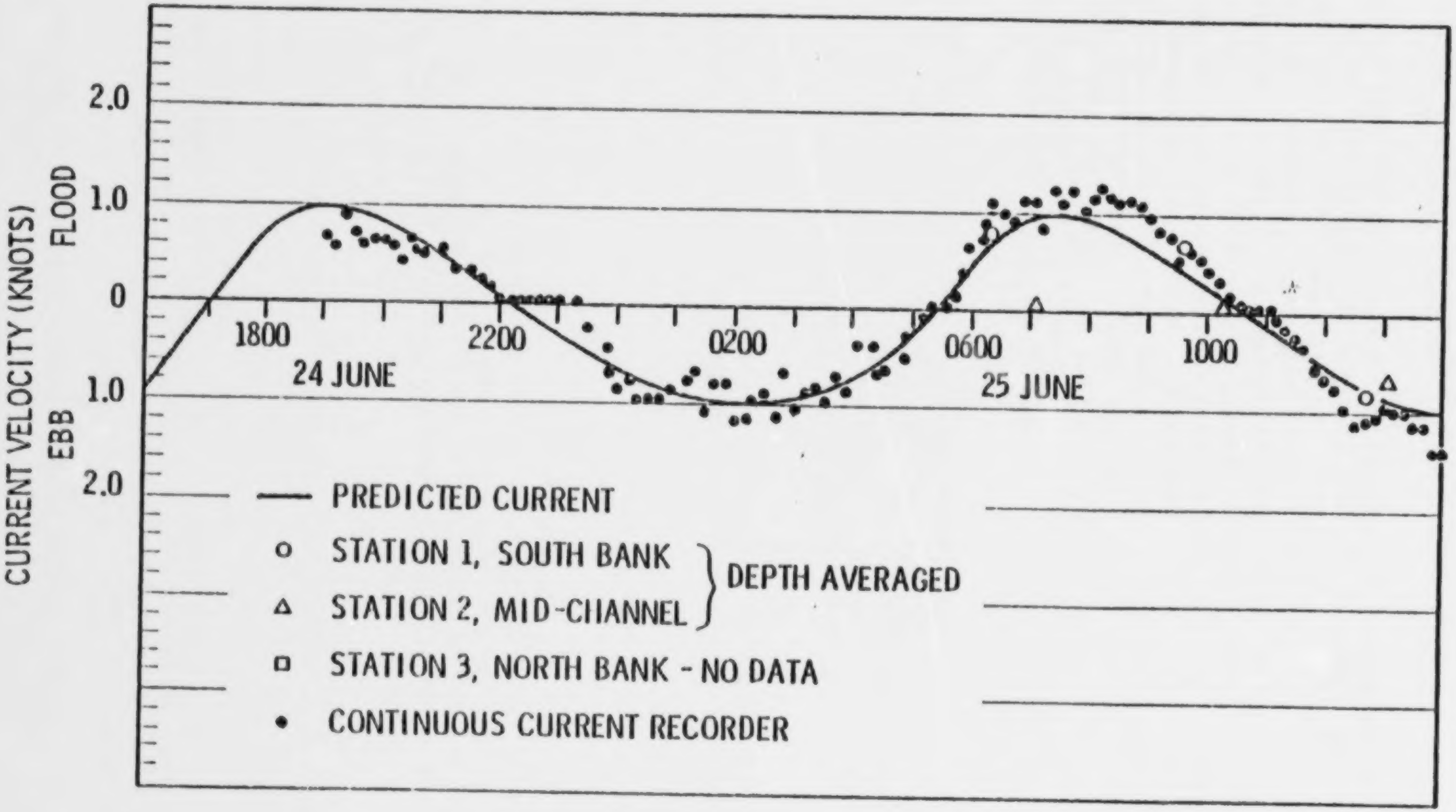


FIGURE VII.15 JR-10 City Point

Conductivity

The largest variation of conductivity occurred in the longitudinal direction, varying from a maximum of 1260 μmhos at the James River Bridge to a minimum of 225 μmhos at City Point. As shown in Figure VII.16, the conductivity decreased gradually between these two locations. All cross-sectional averages shown in Figures VII.16 through VII.28 are obtained by averaging values measured at three transverse locations across the channel with equal weight. No large conductivity gradients were observed during the sampling program, either in the longitudinal or vertical directions. This absence of a large gradient in either of these two directions indicates the lack of a null zone (area where fresh and saline waters intermix) and is due to the very low fresh-water discharge during the June 25-28 sampling program. The average fresh-water discharge of the James River at Carterville, Virginia is 200,000 ℓ/sec (7,000 ft^3/sec). On June 25-28 the average discharge was 51,000 ℓ/sec (1,800 ft^3/sec).

Figure VII.17 shows the variations of conductivity between the near surface, mid-depth, and near-bottom waters in the main flow channel during flood tide. Vertical variations in conductivity during the sampling program were slight. The largest variation occurred at JR-4, west of Swann Point, where the conductivity increased from 630 μmhos at the surface to 740 μmhos at the bottom.

Lateral variations in conductivity between the south bank, mid-channel, and north bank during flood are shown in Figure VII.18. The lateral variations of conductivity were also slight. The largest variations in the cross-channel conductivity distribution occurred at JR-3, Hog Island and JR-9, Jordan Point. At Hog Island the conductivity varied from 1030 μmhos on the south side, to 980 μmhos in mid-channel, and 950 μmhos on the north side. This cross-channel variation can be attributed to the presence of a flood-flow channel on the south side of the water way and an ebb-flow channel on the north side. At Jordan Point the conductivity varied from 330 μmhos on the south side of the channel to 260 μmhos on mid-channel and on the north side of the channel. The higher value on the south side is probably due to industrial discharges from Bailey Creek with conductivities as high as 1500 μmhos.

pH

The greatest variations of pH in the James River water during the June 25-28 sampling program occurred in the longitudinal direction, where it decreased in the upstream direction until the vicinity of Hopewell where the pH increased dramatically. Figure VII.19 illustrates the upstream changes during flood, ebb, and slack flows. During flood the depth-averaged pH at JR-1, James River Bridge was 7.7 and decreased to 7.0 at JR-7, Windmill Point. The pH then increased slightly to 7.1 at Jordan Point and Bailey Bay. At City Point the pH increased dramatically to 8.5.

Figure VII.20 which is the vertical variation of pH in the main flow channel during flood, indicates very little variation with depth. The greatest variations occurred at JR-8, 9, and 10 where the pH of the near bottom water was two units greater than the near surface water.

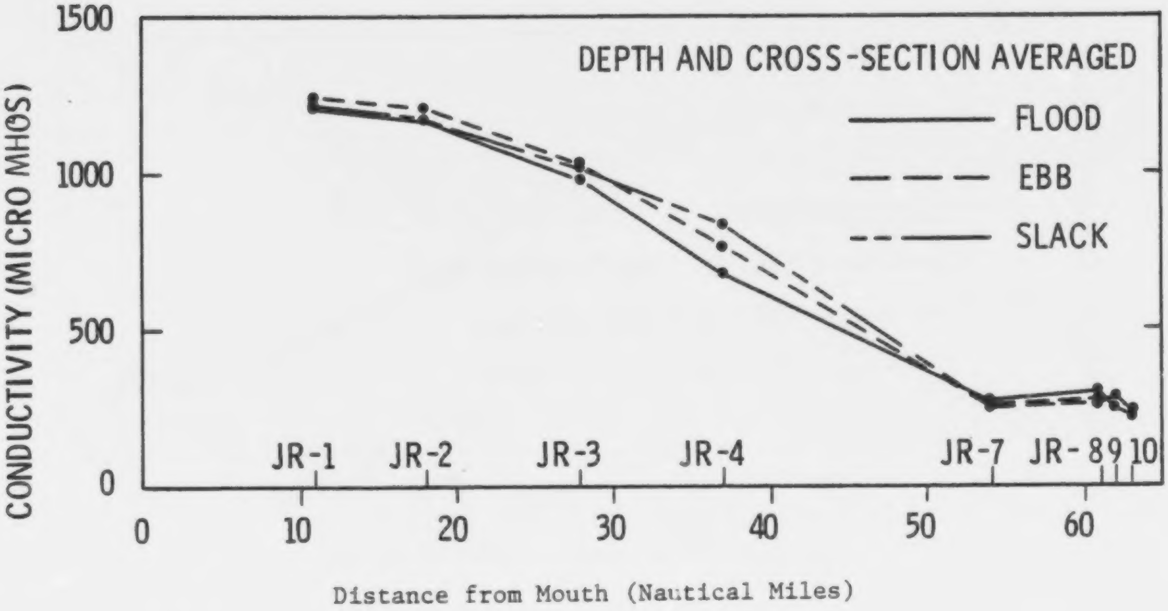


FIGURE VII.16. Average Conductivity as a Function of Tidal Stage

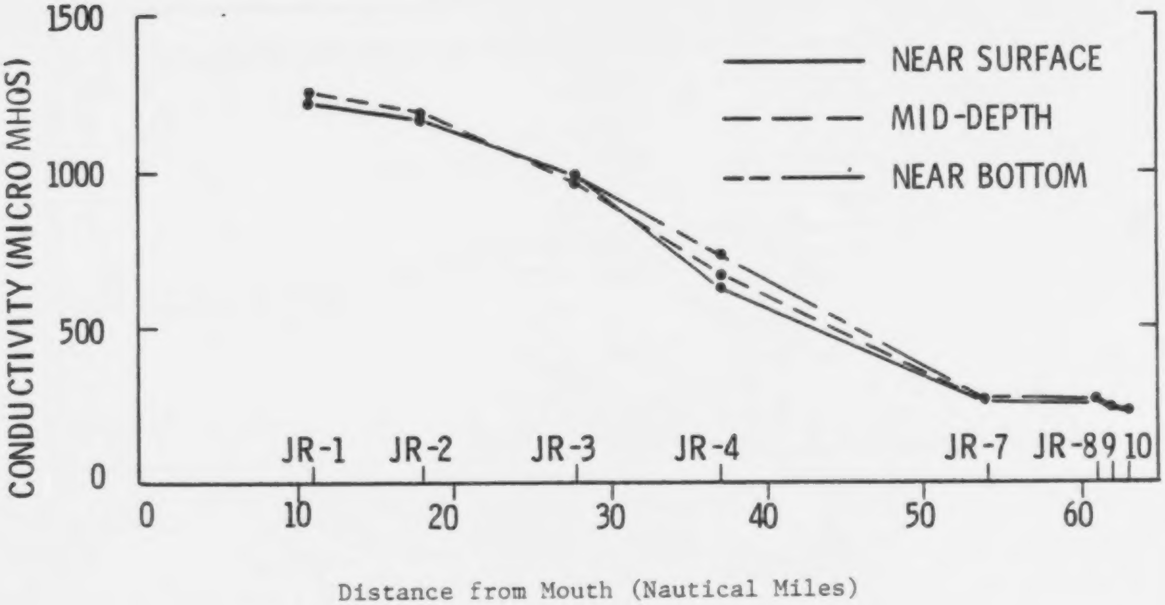


FIGURE VII.17. Average Conductivity as a Function of Depth

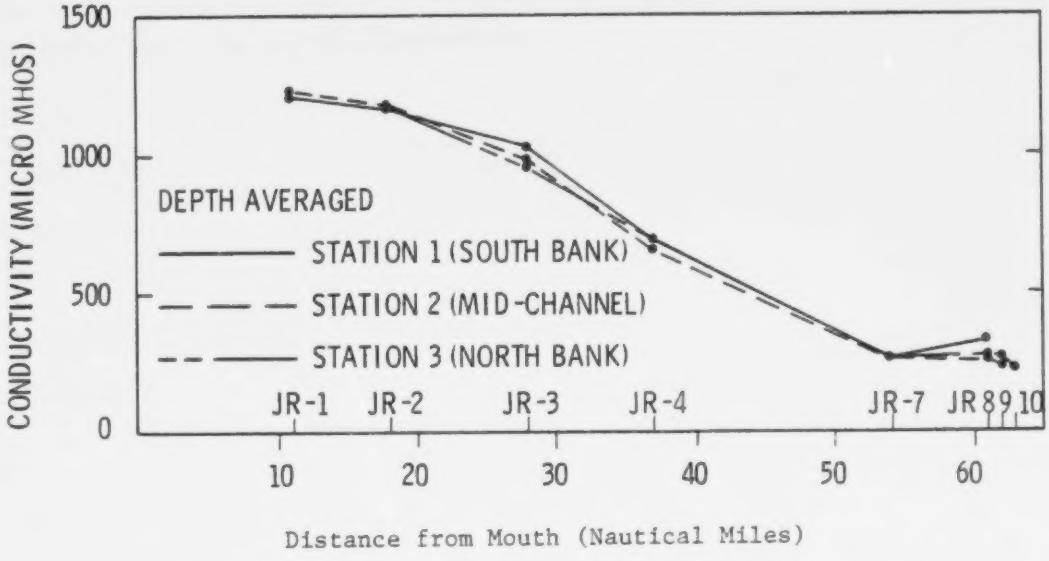


FIGURE VII.18. Lateral Variation of Average Conductivity

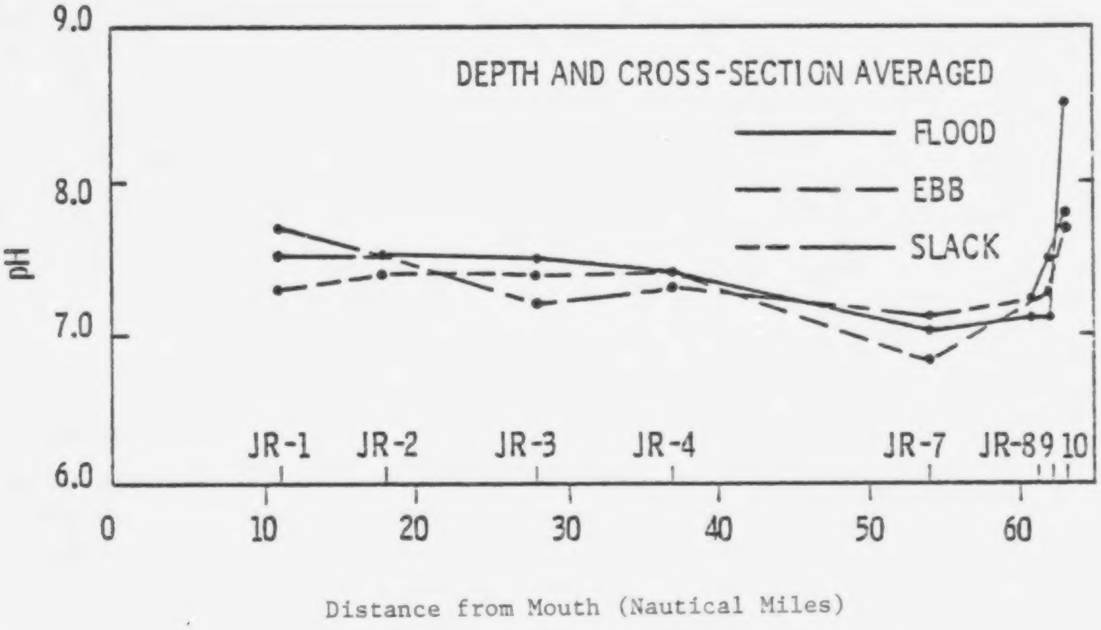
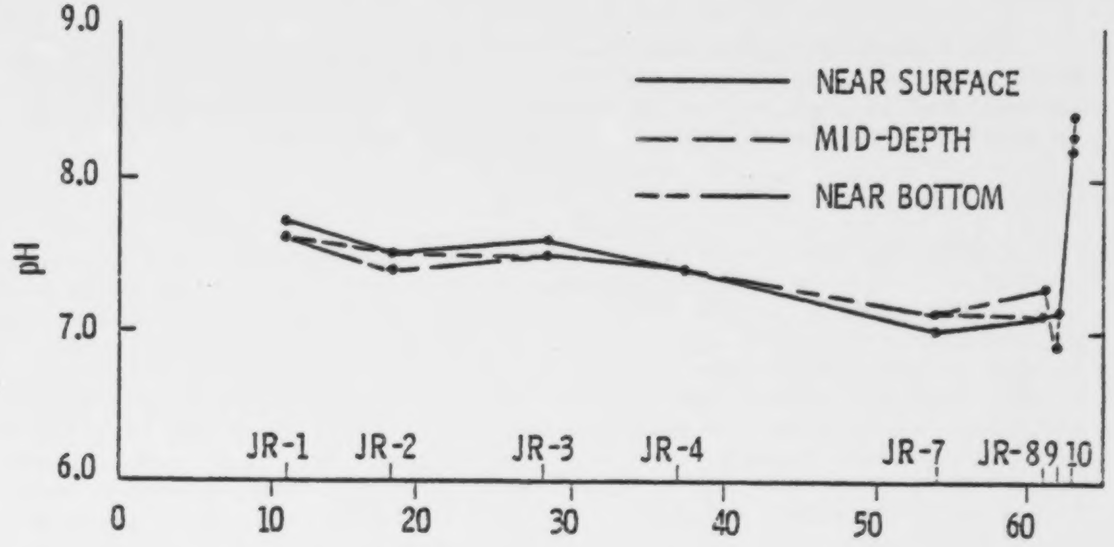


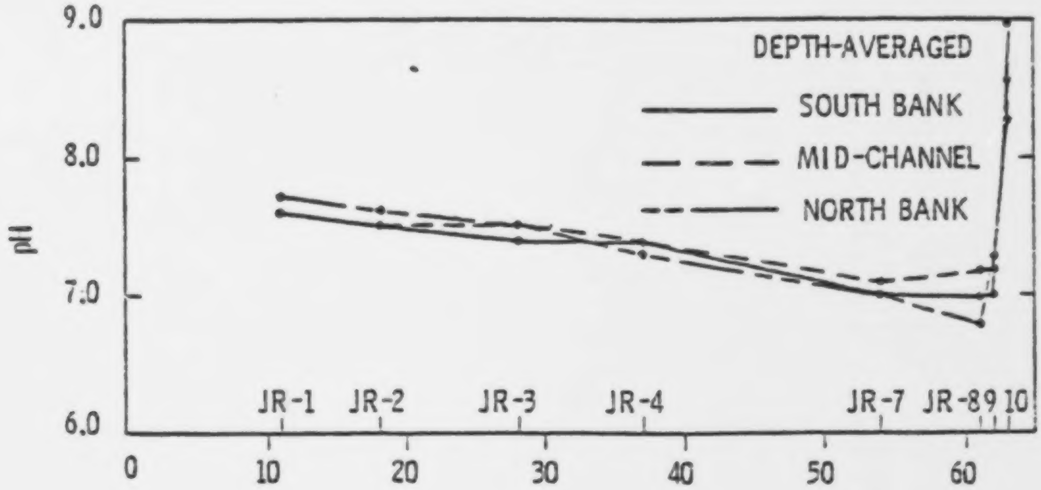
FIGURE VII.19. Longitudinal Variation of pH



Distance from Mouth (Nautical Miles)

FIGURE VII.20. Vertical Variation of pH in Main Flow Channel During Flood

The lateral variations of pH, as shown in Figure VII.21, were of a greater magnitude than the vertical variations. At JR-10, City Point during flood the depth-averaged pH varied from 8.3 on the south side of the waterway to 9.0 on the north side.



Distance from Mouth (Nautical Miles)

FIGURE VII.21. Lateral Variation of pH During Flood

The highest pH during the June 25-28 sampling program was observed at the mouth of Bailey Creek during ebb with a measurement of 11.0. The high pH values found at JR-8, 9, and 10 probably can be attributed to the high pH of industrial discharges into Bailey Creek and Bailey Bay.

Dissolved Oxygen

During the June 25-28 sampling program dissolved oxygen (DO) ranged from a value of 0 mg/ℓ (ppm) in Bailey Creek to 9.2 mg/ℓ (ppm) in the north side of the channel opposite Jordan Point. Dissolved oxygen levels remained unchanged or increased slightly in the upstream direction from James River Bridge (JR-1) to west of Swann Point (JR-4) where the average concentrations were between 6 mg/ℓ (ppm) and 7 mg/ℓ (ppm) (Figure VII.22). From JR-4 to Jordan Point (JR-8) dissolved oxygen levels decreased dramatically during flood and slack waters to concentrations between 2 mg/ℓ and 3 mg/ℓ (ppm). Dissolved oxygen levels increased to concentrations of 4 mg/ℓ to 6 mg/ℓ (ppm) between Jordan Point and City Point. The tidal phase variations of dissolved oxygen were small in the lower tidal James River but were large in the upper portion, varying from 2.5 mg/ℓ (ppm) during flood stage to 5.5 mg/ℓ (ppm) during ebb stage at Jordan Point.

Generally, dissolved oxygen decreases with the depth as shown in Figure VII.23; however, in the upper reaches of the River the depth variation was slight. Between James River Bridge and Hog Island, dissolved oxygen levels varied by approximately 1 mg/ℓ (ppm) between the near surface and near bottom waters in the main flow channel during flood.

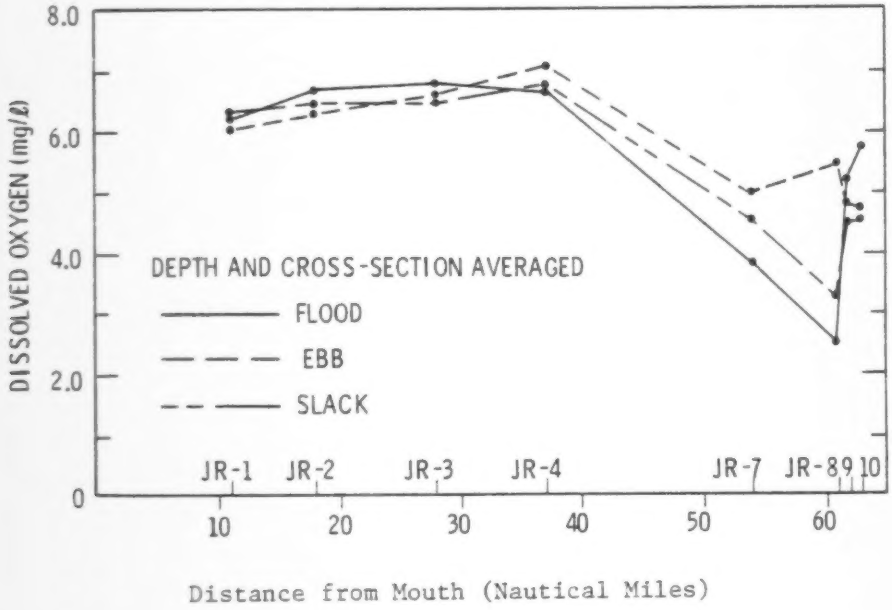


FIGURE VII.22. Variation of Dissolved Oxygen with Tidal Stage

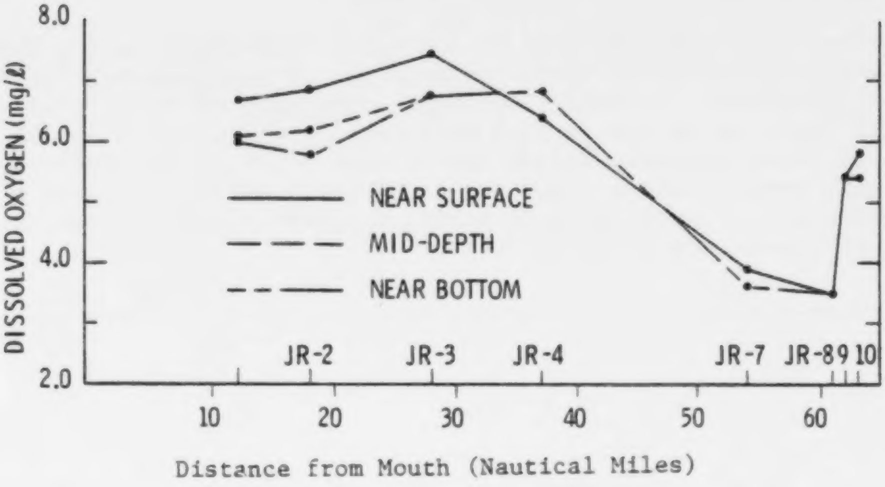


FIGURE VII.23. Variation in Dissolved Oxygen with Depth

The lateral variation of dissolved oxygen, shown in Figure VII.24 was quite erratic. The largest cross-channel variations occurred at City Point where the influence of Bailey Creek appears to be quite large along the south bank. Here the depth-averaged, cross-channel dissolved oxygen levels during flow stage varied from 0.3 mg/ℓ (ppm) on the Bailey Creek side of the channel (south bank) to 6 mg/ℓ (ppm) on the north bank.

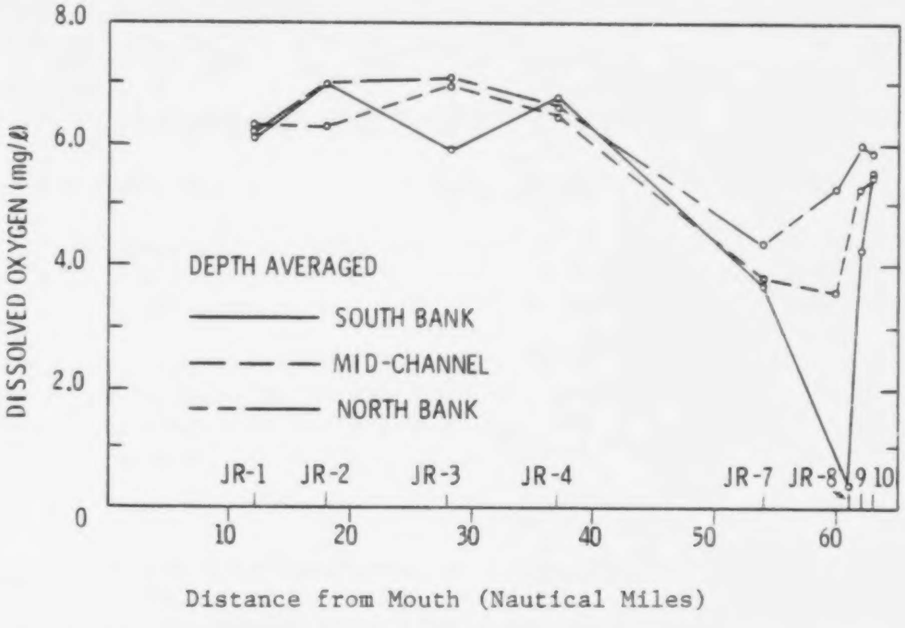


FIGURE VII.24. Lateral Variation in Dissolved Oxygen Content

Suspended Sediment

The suspended sediment load of the tidal James River during the June 25-28 sampling program was quite variable in the longitudinal, lateral, and vertical dimensions. Suspended sediment loads were observed to be as high as 98.6 mg/ℓ (ppm) and as low as 11.1 mg/ℓ (ppm). Generally, as shown in Figure VII.25, high suspended solids levels were found in the lower portion of the estuary between Newport News and Hog Island, and in the upper portion around Hopewell. The levels were generally lower in the stretch of river between Hog Island and Windmill Point.

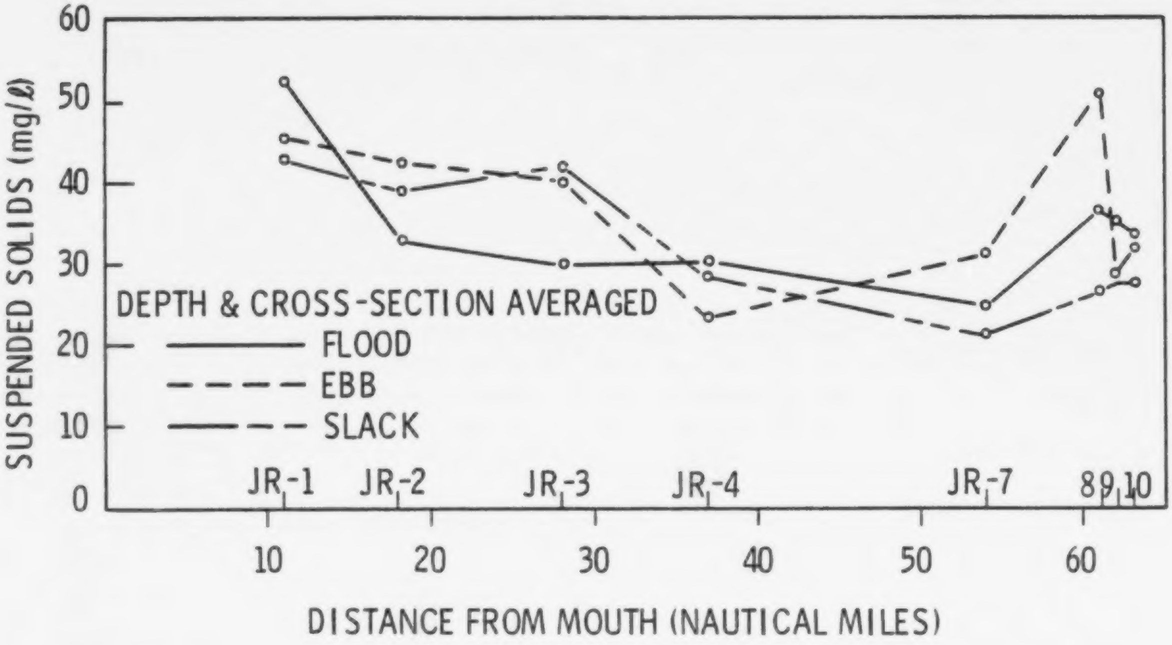


FIGURE VII.25. Longitudinal Variation of Suspended Solids

Figure VII.26 shows the vertical variation of suspended solids in the main flow channel during flood. The suspended solids levels were observed to be lowest in the near surface waters and increase with depth.

The lateral distribution of suspended solids, shown in Figure VII.27, was much more variable than either the longitudinal or vertical distribution. The suspended solids levels in the main flow channel were generally lower than along the subtidal flats on either side of the flow channel.

Kepone

Longitudinal variations of Kepone associated with suspended sediment during the June 25-28 sampling program are shown in Figure VII.28. Kepone levels were found to generally decrease in the downstream direction from the source area near Hopewell. The highest Kepone levels were found in Bailey Creek suspended sediment with levels exceeding 1.0 μg/g (ppm).

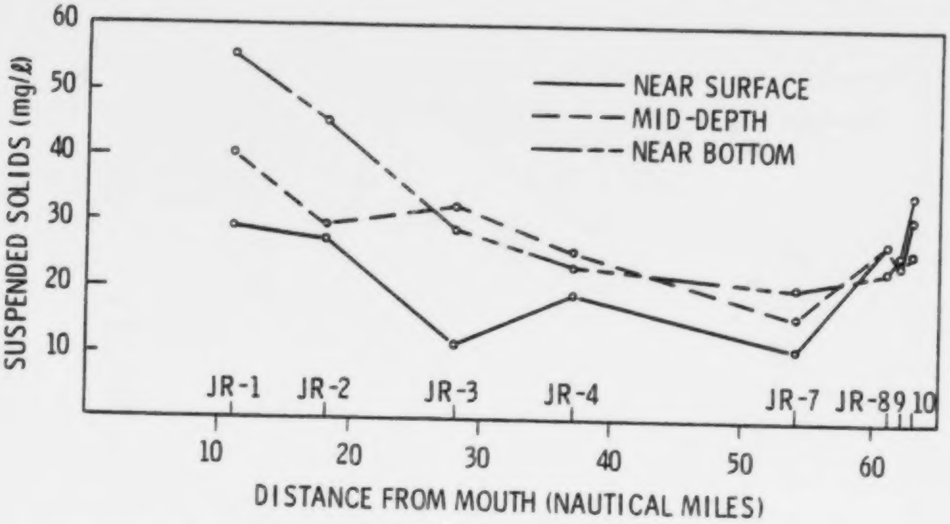


FIGURE VII.26. Vertical Variation of Suspended Solids in Main Flow Channel During Flood

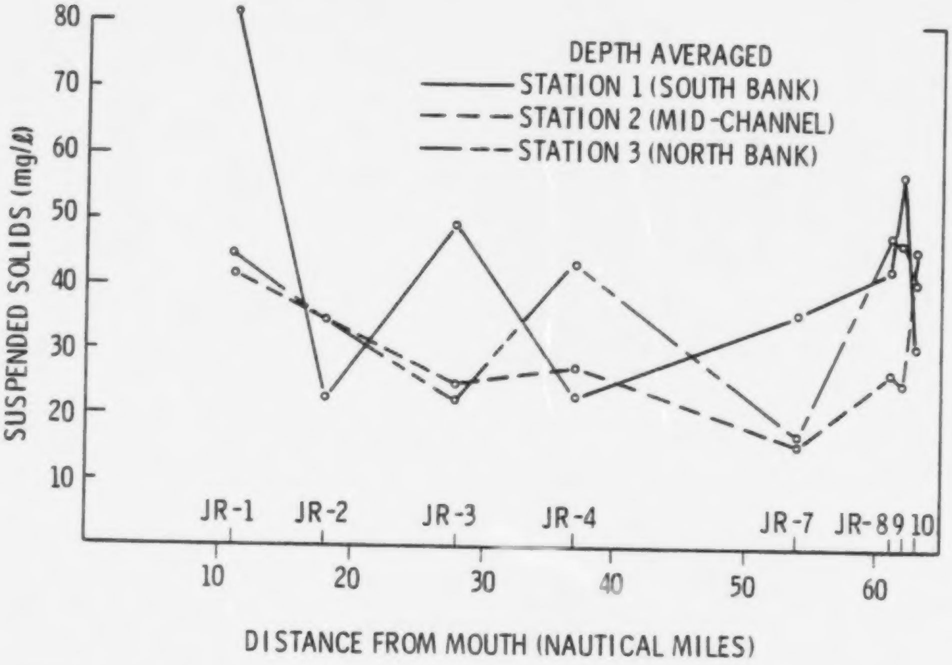


FIGURE VII.27. Lateral Variation of Suspended Solids During Flood

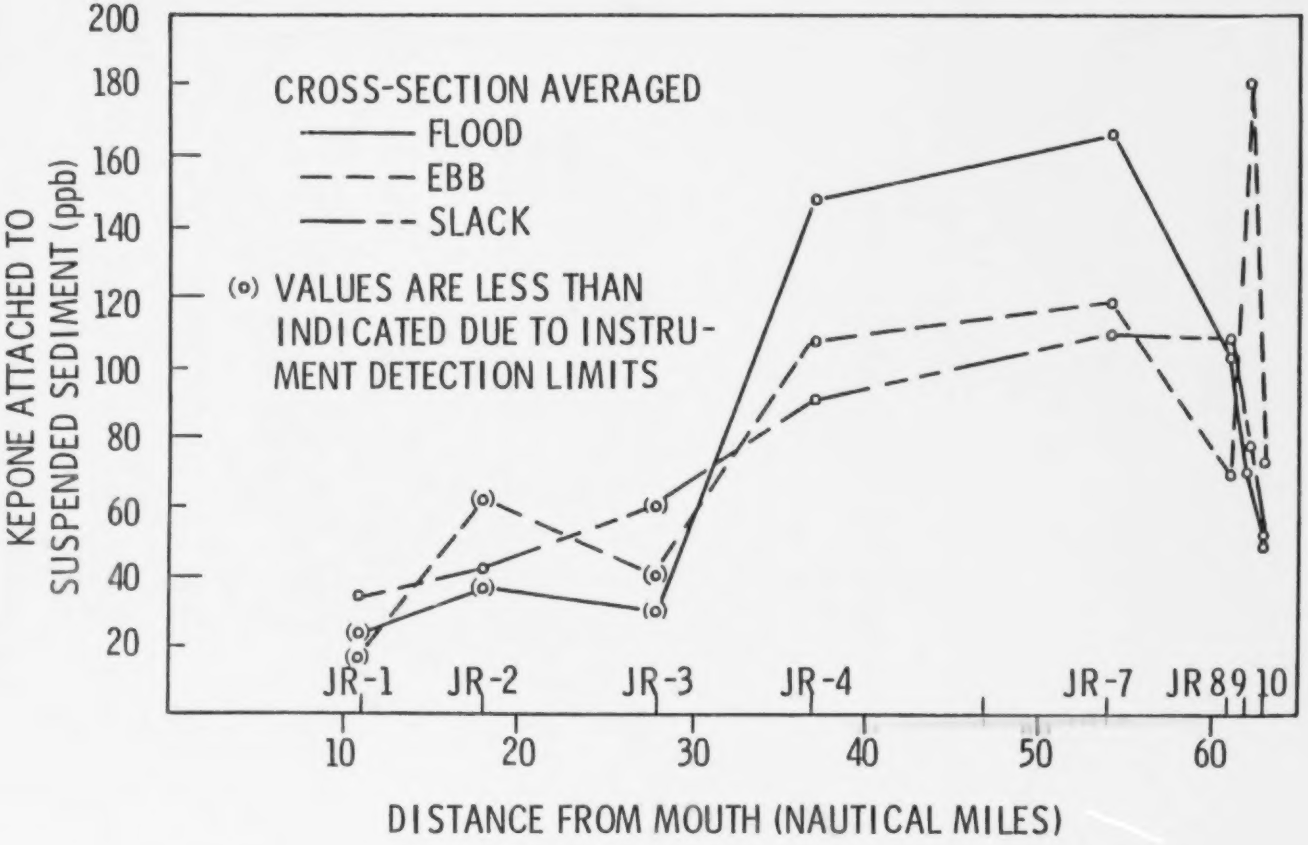


FIGURE VII.28. Longitudinal Variation of Kepone Attached to Suspended Sediment

The lowest levels were found at the furthest downstream sampling location at the James River Bridge with levels less than 11 ng/g (ppb). The largest longitudinal decrease in concentrations occurred between Hog Island and just west of Swann Point. Large lateral variations in Kepone levels attached to the suspended sediment were observed. These lateral variations are shown in Figure VII.29. The largest lateral variations occurred between Hog Island and Jordan Point.

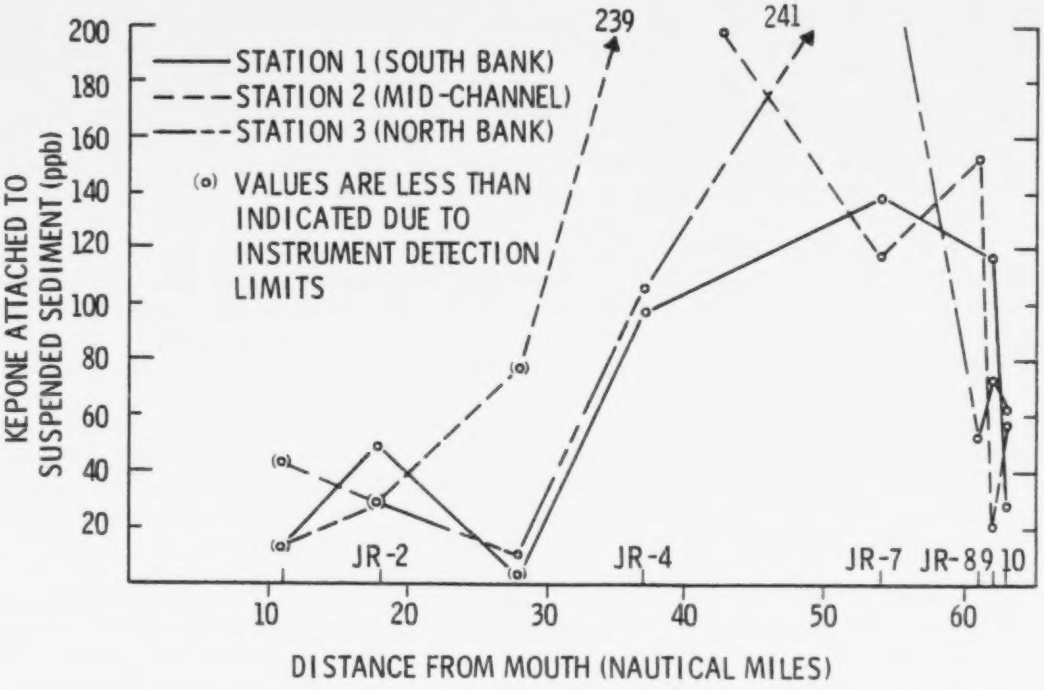


FIGURE VII.29. Lateral Variation of Kepone Attached to Suspended Sediment During Flood

MATHEMATICAL SIMULATION OF TRANSPORT OF SEDIMENT AND KEPONE IN THE JAMES RIVER ESTUARY

Kepone originally released into the James River estuarine system has been dispersed by turbulent mixing, river inflow and tidal flow. Much of the Kepone has been adsorbed by river sediments (both organic and inorganic materials) which may create a significant pathway to man through the aquatic biota. Adsorption by the suspended sediments and/or possible desorption from them are important mechanisms affecting the migration of Kepone through the James River estuarine system (EPA, 1976; Smith, 1976). This is seen by the deposition and resuspension of contaminated sediments in the River.

Several model concepts were evaluated for use in the Kepone project. However, as revealed by a recent workshop on the evaluation of mathematical models (Oak Ridge National Laboratory, 1978) there are only two computer models presently available to calculate migration of contaminants by taking into account the interaction between the contaminants and sediment (e.g., contaminant adsorption by sediment or desorption from sediment, deposition and resuspension of contaminated sediment). The two are the FETRA and SERATRA codes (Onishi et al., 1976; Onishi, 1977a, 1977b). Both models are time-dependent, two-dimensional transport models which calculate the migration of sediment and dissolved and particulate pollutants by including the interaction between sediment and pollutants. The FETRA model solves longitudinal and lateral distributions of these substances, while SERATRA predicts longitudinal and vertical concentrations. Although the SERATRA code was judged to be a verified model by participants of the mathematical model evaluation workshop (Oak Ridge National Laboratory, 1978), the FETRA code was selected for this study, because of the importance of lateral distribution of Kepone as well as the longitudinal distributions of Kepone in the River.

Hence, the mathematical simulation of Kepone migration in the tidal James River was conducted by applying the finite element sediment and contaminant transport model, FETRA (Onishi et al., 1976; and Onishi and Ecker, 1977), to the River between Bailey and Burwell Bays. Both time-dependent, one-dimensional (longitudinal) simulation and time-dependent, two-dimensional (longitudinal and lateral) simulation were attempted. However, due to the time limitation, only computer results obtained by one-dimensional transport simulation through application of the FETRA code and the one-dimensional hydrodynamic model, EXPLORE (Baca et al., 1973) are presented here. Model computations were conducted to predict the migration of sediments and Kepone by taking into account sediment-Kepone interactions in the James River.

Sediment transport was modeled for three sediment types (i.e., cohesive and noncohesive sediments and organic matter). Simulation of Kepone transport was initiated for dissolved and particulate Kepone (attached to sediments). Particulate Kepone was analyzed separately for that adsorbed by sediment in each sediment type.

Mathematical Model Formulation of FETRA Code

The FETRA code consists of the following three submodels: (1) sediment transport model, (2) dissolved contaminant transport model, and (3) particulate contaminant transport model. A brief description of these models is presented here and further detailed model formulations are described in Appendix M.

Sediment Transport Model--

Transport of cohesive sediment (silt and clay), noncohesive sediment (sand), and organic material (that being transported independently with sand, silt and clay) are modeled separately since movements of sediments and adsorption capacity vary significantly. The model includes the effects of:

1. convection and dispersion of materials
2. fall velocity and cohesiveness
3. deposition on the river bed
4. resuspension from the river bed (bed erosion and armoring)
5. tributaries

Sediment mineralogy and water quality effects are implicity included through the effects of 2, 3, and 4 above.

The governing equation of sediment transport is a general form of convection-equation as shown by

$$\frac{\partial \bar{C}_j}{\partial t} + \left(\bar{U} - \frac{D_{x_j}}{h}\frac{\partial h}{\partial x}\right)\frac{\partial \bar{C}_j}{\partial x} + \left(\bar{V} - \frac{D_{y_j}}{h}\frac{\partial h}{\partial y}\right)\frac{\partial \bar{C}_j}{\partial y}$$

$$= \frac{\partial}{\partial x}\left(K_{x_j}\frac{\partial \bar{C}}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{y_j}\frac{\partial \bar{C}}{\partial y}\right) + \frac{S_{R_j}}{h} - \frac{S_{D_j}}{h} \qquad (1)$$

where

$\bar{C}_j$ = depth averaged concentration of sediment for jth type sediment

D_{x_j}, D_{y_j} = dispersion coefficient for longitudinal and lateral directions, respectively for jth sediment caused by velocity nonuniformity

h = water depth

$K_{x_j} = D_{x_j} + \varepsilon_{x_j} \approx D_{x_j}$

$K_{y_j} = D_{y_j} + \varepsilon_{y_j} \approx D_{y_j}$

t = time

$\bar{U}$, $\bar{V}$ = depth averaged velocity in longitudinal and lateral directions, respectively

x, y, z = longitudinal, lateral, and vertical directions in Cartesian coordinates, respectively

S_{D_j} = sediment deposition rate per unit bed surface area for jth sediment type

S_{R_j} = sediment erosion rate per unit bed surface area for jth sediment type

ε_{x_j}, ε_{y_j} = turbulent diffusion coefficient for longitudinal and lateral directions, respectively for jth sediment

As stated above, detailed derivation of the above equation and its boundary conditions are described in Appendix M.

Dissolved Contaminant Transport Model--

In this study, it was assumed that the association of dissolved contaminants (such as dissolved Kepone) with suspended sediments (both organic and inorganic matter) is the primary mechanism of contaminant uptake. The model includes effects of:

1. convection and dispersion of contaminant within the River
2. adsorption (uptake) of dissolved contaminant by sediments (cohesive and noncohesive inorganic sediments and organic matter) or desorption from the sediments into water
3. chemical and biological decay of contaminant
4. tributaries. (Contaminant contributions from wastewater discharges, overland runoff flow, fallout and ground water to a river system may be treated as a part of tributary contributions.)

Effects of water quality (e.g., pH, water temperature, salinity, etc.) and sediment characteristics, such as clay minerals, are taken into account through changes in the distribution (or partition) coefficient, K_{d_j}.

The governing equation for this case is:

$$\frac{\partial \bar{G}_w}{\partial t} + \left(\bar{U} - \frac{D_{x_w}}{h}\frac{\partial h}{\partial x}\right)\frac{\partial \bar{G}_w}{\partial x} + \left(\bar{V} - \frac{D_{y_w}}{h}\frac{\partial h}{\partial y}\right)\frac{\partial \bar{G}_w}{\partial y}$$

$$= \frac{\partial}{\partial x}\left(k_{x_w}\frac{\partial \bar{G}_w}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{y_w}\frac{\partial \bar{G}_w}{\partial y}\right) - \left(\lambda + \sum_j K_j K_{d_j} \bar{C}_j\right)\bar{G}_w$$

$$+ \sum_j K_j K_{p_j} \bar{C}_j G_j \qquad (2)$$

In addition to the previously defined symbols:

ε_{x_w}, ε_{y_w} = longitudinal and lateral diffusion coefficients (these are practically the same as ε_{x_j}, ε_{y_j})

D_{x_w}, D_{y_w} = longitudinal and lateral dispersion coefficients of dissolved contaminant, respectively (these are practically the same as D_{x_j}, D_{y_j})

K_{d_j} = distribution (or partition) coefficient between dissolved contaminant and particulate contaminant associated with jth sediment

K_j = mass transfer rate of contaminant for jth sediment

K_{p_j} = nondimensional coefficient: equal unity if contaminant adsorption or desorption associated with jth sediment occurs ($K_{d_j} = 1$); equal zero if neither contaminant adsorption nor desorption associated with jth sediment occurs ($K_{d_j} = 0$)

$K_{x_w} = D_{x_w} + \varepsilon_{x_w} \approx D_{x_w}$

$K_{y_w} = D_{y_w} + \varepsilon_{y_w} \approx D_{y_w}$

G_j = particulate contaminant concentration associated with jth sediment (weight or contaminant per unit weight of sediment)

$\bar{G}_w$ = depth averaged dissolved contaminant concentration (weight of Kepone per unit volume of water)

ε_{x_w}, ε_{y_w} = longitudinal, and lateral diffusion coefficients for dissolved contaminant

λ = chemical and biological decay rate of contaminant

Distribution coefficient, K_{d_j} as mentioned, is defined by:

$$K_{d_j} = \frac{f_{s_j}/M_j}{f_w/V_w} = \frac{f_{s_j}}{f_w C_j} = \frac{G_j}{G_w}$$

where

f_{s_j} = fraction of contaminant sorbed by jth sediment

f_w = fraction of contaminant left in solution

M_j = weight of jth sediment

V_w = volume of water

G_w = dissolved contaminant concentration (weight of contaminant per unit volume of water)

Particulate Contaminant Transport Model--

The transport model of a contaminant (such as Kepone) attached to sediments are solved separately for those adsorbed by cohesive and noncohesive sediments, and organic materials (those being transported independently with the inorganic sediments). This model also includes the effects of:

1. convection and dispersion of particulate contaminant
2. adsorption (uptake) of dissolved contaminant by sediments or desorption from sediments into water
3. chemical and biological decay of contaminant
4. deposition of particulate contaminant on the river bed or resuspension from the river bed
5. tributaries. (contaminant contributions from wastewater discharges, overland runoff flow, fallout and ground water to a river system may be treated as a part of the tributary contributions.)

The equation governing the transport of particulate contaminant is:

$$\frac{\partial G_j}{\partial t} + \left\{\bar{U} - \frac{2\varepsilon_{x_j}}{\bar{C}_j}\frac{\partial \bar{C}_j}{\partial x} - \frac{D_{x_j}}{\bar{C}_j}\frac{\partial \bar{C}_j}{\partial x}\right\}\frac{\partial G_j}{\partial x} + \left\{\bar{V} - \frac{2\varepsilon_{y_j}}{\bar{C}_j}\frac{\partial \bar{C}_j}{\partial y} - \frac{D_{y_j}}{\bar{C}_j}\frac{\partial \bar{C}_j}{\partial y}\right\}\frac{\partial G_j}{\partial y}$$

$$= \frac{\partial}{\partial x}\left(\varepsilon_{x_j}\frac{\partial G_j}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_{y_j}\frac{\partial G_j}{\partial y}\right) - \left(\frac{S_{R_j}}{\bar{C}_j h} + \lambda + K_j\ K_{p_j}\right)G_j$$

$$+ \left(K_j\ K_{d_j}\ G_w + \frac{G_{B_j} S_{R_j}}{\bar{C}_j h}\right) \qquad (3)$$

where

G_{B_j} = particulate contaminant concentration associated with jth sediment in the river bed

The above three equations, together with boundary conditions are solved by the finite element solution technique with the Galerkin weighted residual method.

The FETRA code, consisting of the above three models, then computes the following:

a) Sediment simulation
for any given time,

- longitudinal and lateral distributions of total sediment (sum of suspended and bed load) concentration for each sediment type
- three-dimensional (longitudinal, lateral and vertical) distributions of ratio of different sediment type in the river bed
- change in river bed elevation (elevation changes due to sediment deposition and/or scour)

b) Contaminant simulation
for any given time,

- longitudinal and lateral distributions of dissolved contaminant concentration
- longitudinal and lateral distributions of contaminant concentration adsorbed by sediment for each sediment type
- longitudinal and lateral distribution of concentrations of total particulate contaminants associated with all types of sediment (sum of particulate contaminant concentration for each sediment type)
- three-dimensional distributions of contaminant concentrations in the river bed sediment for each sediment type
- three-dimensional distributions of total contaminant in the river bed

Prior to the application of the FETRA code to the present James River estuary study, the accuracy and convergence of the numerical solutions calculated by the FETRA code were evaluated to confirm the validity of the basic computational scheme of the model. This verification involved solving equations by the FETRA code and comparing the resulting numerical solutions with known analytical solutions to the problems. These results are also shown in Appendix M. Comparison of these results reveals an excellent agreement between the computed and analytical solutions. These results confirm the validity of the basic numerical scheme of the transport model, FETRA.

Computer Simulation Results

The FETRA code was employed in combination with hydrodynamic models to calculate Kepone transport in the tidal James River.

As stated earlier, both one (longitudinal) and two (longitudinal and lateral) dimensional simulations have been attempted. However, due to the time availability, only the computer results obtained by one-dimensional simulation will be presented in this report. The one-dimensional EXPLORE code was used to obtain depth and velocity distributions in the study area. These were in turn fed to the time-dependent, two-dimensional sediment and pollutant transport code, FETRA, to obtain longitudinal distributions of sediment and Kepone in the tidal James River. Hence, the results presented here are vertically and laterally averaged values changing with tidal flow.

The modeling procedure for FETRA involved simulating the transport of sediments (organic and inorganic materials) within the water body. The results were then input to models of dissolved and particulate Kepone in order to observe the interaction between sediment and Kepone. Finally, changes in river bed conditions were recorded, including: (1) river bottom elevation change, (2) ratio of cohesive sediment, noncohesive sediment and organic material, and (3) distribution of Kepone in the river bed.

The model was applied to an 86-km reach between City Point (River Kilometer 123) and Burwell Bay (River Kilometer 37), as shown in Figure VII.30. Mathematical simulation was not extended seaward beyond Burwell Bay because of limitations on the availability of field data necessary to run the hydrodynamic code, EXPLORE. Hence, as will be discussed later the prediction of Kepone levels leaving the James River and entering Chesapeake Bay may be somewhat conservative.

Three flow discharge cases were simulated here: (1) a net fresh-water input discharge of 58.3 m^3/sec (2,060 cfs), (2) a net fresh-water input discharge of 247 m^3/sec (8,700 cfs), and (3) a net fresh-water input discharge of 681 m^3/sec (24,000 cfs) (all measured at City Point). The net fresh-water input discharge of 58.3 m^3/sec at City Point corresponds to that of approximately the 10 percentile discharge (Virginia Department of Conservation and Economic Development, 1970) (i.e., 10% of the time of the year the net fresh-water input discharge is 58.3 m^3/sec or less). The second discharge of 247 m^3/sec corresponds to the average annual discharge, and the third discharge of 681 m^3/sec corresponds to approximately the 90 percentile discharge.

Test conditions for these three cases are shown in Table VII.11. The river sediments consist of cohesive sediment (silt and clay), organic matter and sand. Their particle sizes were assumed to be 0.030 mm, 0.100 mm and 0.150 mm, respectively. Longitudinal dispersion coefficients for all sediment and dissolved Kepone, D_{x_j} and D_{x_w}, were assumed to be 14 m^3/sec. While all longitudinal diffusion coefficients, ε_{x_j} and ε_{x_w}, were assumed to be 0.14 m^2/sec. Since there have not been any field or laboratory studies to estimate three parameters, M_j, τ_{cR_j}, and τ_{cD_j} to estimate erosion and deposition rates, S_{R_j} and S_{D_j} (see Equations 15 and 16 in Appendix M), they were determined to fit measured sediment concentrations for the case of the fresh-water discharge of 58.3 m^3/sec. The bed shear stresses at each location, for each time step, were calculated by the FETRA code internally with a known velocity.

Since the new contribution of Kepone from tributaries to the James River is presently very small as compared to the total amount of Kepone already in the James River, and also the flow rate of the tributaries is insignificant as compared to the James River tidal flow rate, it was assumed that no Kepone was added into the James River through tributaries during the simulation period. As discussed in Chapter IV, there is no significant chemical and biological degradation, or volatilization. Therefore, the decay rate, λ, was assumed to be zero in this study.

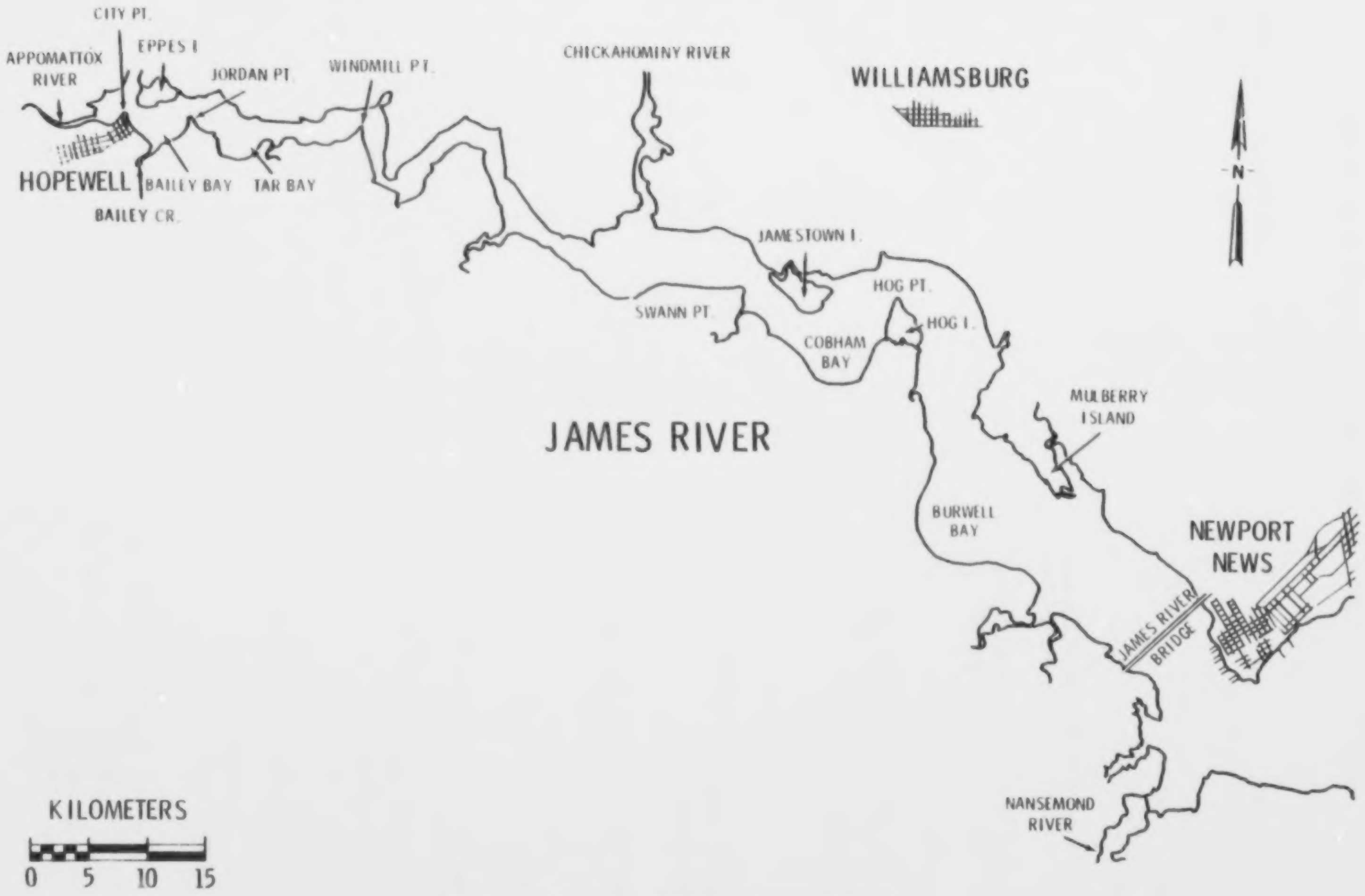

APPOMATTOX RIVER
CITY PT.
EPPES I
JORDAN PT.
WINDMILL PT.
HOPEWELL
BAILEY BAY
TAR BAY
BAILEY CR.
CHICKAHOMINY RIVER
WILLIAMSBURG
N
JAMESTOWN I.
HOG PT.
SWANN PT.
HOG I.
COBHAM BAY
JAMES RIVER
MULBERRY ISLAND
BURWELL BAY
NEWPORT NEWS
JAMES RIVER BRIDGE
NANSEMOND RIVER
KILOMETERS
0
5
10
15

FIGURE VII.30. Tidal James River

TABLE VII.11. TEST CONDITIONS FOR KEPONE SIMULATION

	Case 1	Case 2	Case 3
Fresh-water Discharge (m^3/sec)	58.3	247	681
River Sediment Size (mm)			
Cohesive sediment	0.030	0.030	0.030
Organic matter	0.100	0.100	0.100
Sand	0.150	0.150	0.150
Longitudinal Dispersion Coefficients for all Sediment and Kepone (m^2/sec)	14	14	14
Longitudinal Diffusion Coefficients for all Sediment and Kepone (m^2/sec)	0.14	0.14	0.14
Kepone Decay Rate (1/hr)	0	0	0
Kepone Distribution Coefficients (cm^3/g)			
Associated with cohesive sediment	10,000	10,000	10,000
Associated with organic matter	20,000	20,000	20,000
Associated with sand	1,000	1,000	1,000
Kepone Mass Transfer Rate (1/hr)	1	1	1
Initial Bed Sediment Constituents (%)			
Cohesive sediment	80	80	80
Organic Matter	15	15	15
Sand	5	5	5
Boundary Conditions During Ebb Tide			
Sediment Concentrations at City Point (mg/ℓ)			
Cohesive sediment	24	32	52
Organic matter	4.5	6	9.8
Sand	1.5	2	3.2
Kepone Concentrations at City Point			
Dissolved (μg/ℓ)	0.007	0.007	0.007
Particulate (μg/g) associated with			
Cohesive sediment	0.045	0.045	0.045
Organic Matter	0.090	0.090	0.090
Sand	0.0045	0.0045	0.0045
Boundary Conditions During Flood Tide			
Sediment Concentrations at Burwell Bay (mg/ℓ)			
Cohesive sediment	24	32	52
Organic matter	4.5	6	9.8
Sand	1.5	2	
Kepone Concentrations at Burwell Bay			
Dissolved (μg/ℓ)	0.007	0.007	0.007
Particulate (μg/g) associated with			
Cohesive sediment	0.032	0.032	0.032
Organic matter	0.064	0.064	0.064
Sand	0.0032	0.0032	0.0032

As discussed in Chapter IV, the distribution coefficient of Kepone for water and sediments was theoretically estimated to be 5.7 x 10^4 ∿ 1.1 x 10^5 cm^3/g, if organic materials are not considered. Field and laboratory data obtained by Battelle and the Virginia Institute of Marine Science (Huggett et al., 1978) reveal that the K_d value for the James River sediment varies from approximately 2 x 10^3 to 2 x 10^4 cm^3/g with the exception of Bailey Creek which has a K_d value of up to 3 x 10^5 cm^3/g. As shown in Figure IV.2 of Chapter IV, K_d values depend strongly on sediment sizes and organic matter, as well as some water quality parameters. Based on results obtained by the theoretical analysis (also shown in Figure IV.2) and available measured data obtained in the James River and in laboratories, K_d values for cohesive sediment, organic matter and sand were selected to be 1 x 10^4, 2 x 10^4, and 1 x 10^3 cm^3/g for the present mathematical simulation. Since the ratio of cohesive sediment, organic material and sand among the James River sediment was initially set to be 0.80, 0.15, and 0.05 for this study, the K_d value for the composite James River sediment corresponds to 11,050 cm^3/g.

The mass transfer rate for Kepone, K_j, was assumed to be 1.0/hr for all sediment types. Hence adsorption and/or desorption mechanisms at a given condition are assumed to be completed in 1 hr to reach equilibrium. Sediment and Kepone concentrations used for boundary conditions are also listed in Table VII.1. Note that most measured dissolved Kepone concentrations were below the detection limit which is approximately 0.01 to ∿0.005 μg/ℓ in water. From the measured particulate Kepone concentration and the K_d value, the expected dissolved Kepone concentration is somewhat below but roughly the same order of magnitude of the detection limit. Thus, for this study, as a conservative estimate, the dissolved Kepone concentrations assigned as boundary conditions were set to be 0.007 μg/ℓ, as shown in Table VII.11.

Since the field data collected by Battelle in June 1977 are those for 58.3 m^3/sec, a major portion of the calibration and verification of the FETRA code was conducted for this discharge. After the model was calibrated, the other two discharge cases were tested without changing or readjusting the FETRA code except for boundary conditions of sediment concentrations. In order to take into account the effect of the tide, the computer simulation was conducted for 31 days with a 30-min time step by simulating tidal motion. All computer results for sediment and Kepone concentrations presented here were obtained on the 31st day of the simulation.

Simulation of sediment and Kepone transport was conducted for each of the following substances: (1) cohesive sediment (clay and silt), (2) organic matter moving independent of cohesive sediment, (3) sand, (4) dissolved Kepone (5) particulate Kepone attached to cohesive sediment, (6) particulate Kepone associated with organic matter, and (7) particulate Kepone adsorbed on sand. In this chapter only major results of Kepone simulation are described. A more detailed discussion of computer results is presented in Appendix M. Discussion of the simulation results are presented here as follows: (1) calibration of the model, (2) verification of the model, (3) summary of computer simulation results on Kepone transport, (4) sensitivity analysis, and (5) Kepone cleanup activities.

Calibration of the Model--

Calibration of a mathematical model is one of the most important aspects of the simulation process. Calibration is usually performed by "tuning" a model to reproduce a known condition by adjusting some model parameters. As shown in Table VII.11, in the present study most of the parameters (such as Kepone distribution coefficients, the turbulent diffusion coefficient, sediment sizes, sediment fall velocity, etc.) were determined by theoretical and experimental analyses and field conditions prior to the model simulation rather than by adjustment to match computer results of field data. Hence, the only parameters which can be changed to fit simulation results to the measured data are a dispersion coefficient and three parameters which calculate deposition and erosion rates of sediment. Thus, the major calibration effort was exercised to reproduce sediment distribution patterns similar to the actual longitudinal distribution of sediment concentrations for the 86-km study reach measured by Battelle during June 25-28, 1977.

As a result of numerous trial runs after adjusting the parameters, final calibration computer results for the fresh-water discharge of 58.3 m^3/sec are shown in Figures VII.31 through VII.33. These figures show computed longitudinal variations of total sediment concentration (sum of cohesive sediment, organic matter and sand being transported as suspended and bed loads) at maximum ebb, stack tide and maximum flood, together with measured data obtained by Battelle for the same fresh-water discharge. Comparison of the computer results with the measured data indicate excellent agreement. Although it is possible to improve the model prediction with more fine tuning, it was judged that the model was calibrated successfully. Figure VII.34 shows longitudinal distributions of tidal averaged sediment concentrations for each sediment component (cohesive sediment, organic material and sand) and the total sediment, together with total sediment concentration data obtained by Battelle and by Virginia Institute of Marine Science (VIMS, 1977; Huggett et al., 1978). VIMS data were obtained during August 24-29, 1977. The fresh-water discharge at City Point (River Kilometer 123) during the VIMS sampling period varied from 52.6 cm^3/sec to 32.5 cm^5/sec with a 6-day average of 41.7 cm^3/sec. Although this discharge is slightly less than that which occurred during the Battelle sampling period (58.3 m^3/sec), they are close enough to use for comparison with the computer simulation results. As shown in Figure VII.34, the agreement between the computer and measured results is good. Since the VIMS data were not available until the calibration process was completed, the good agreement of predicted results to VIMS data provides verification of the model to some degree.

Verification of the Model--

The verification of the sediment transport part of the model was conducted for Case 2 (fresh-water discharge of 247 m^3/sec) without changing any of the model parameters. Resulting computer simulation of sediment concentrations are shown in Figures VII.35 and VII.36, together with field data. These figures include sediment concentrations of each type of sediment (cohesive sediment, organic materials or sand) and total sediment (sum of those sediment components).

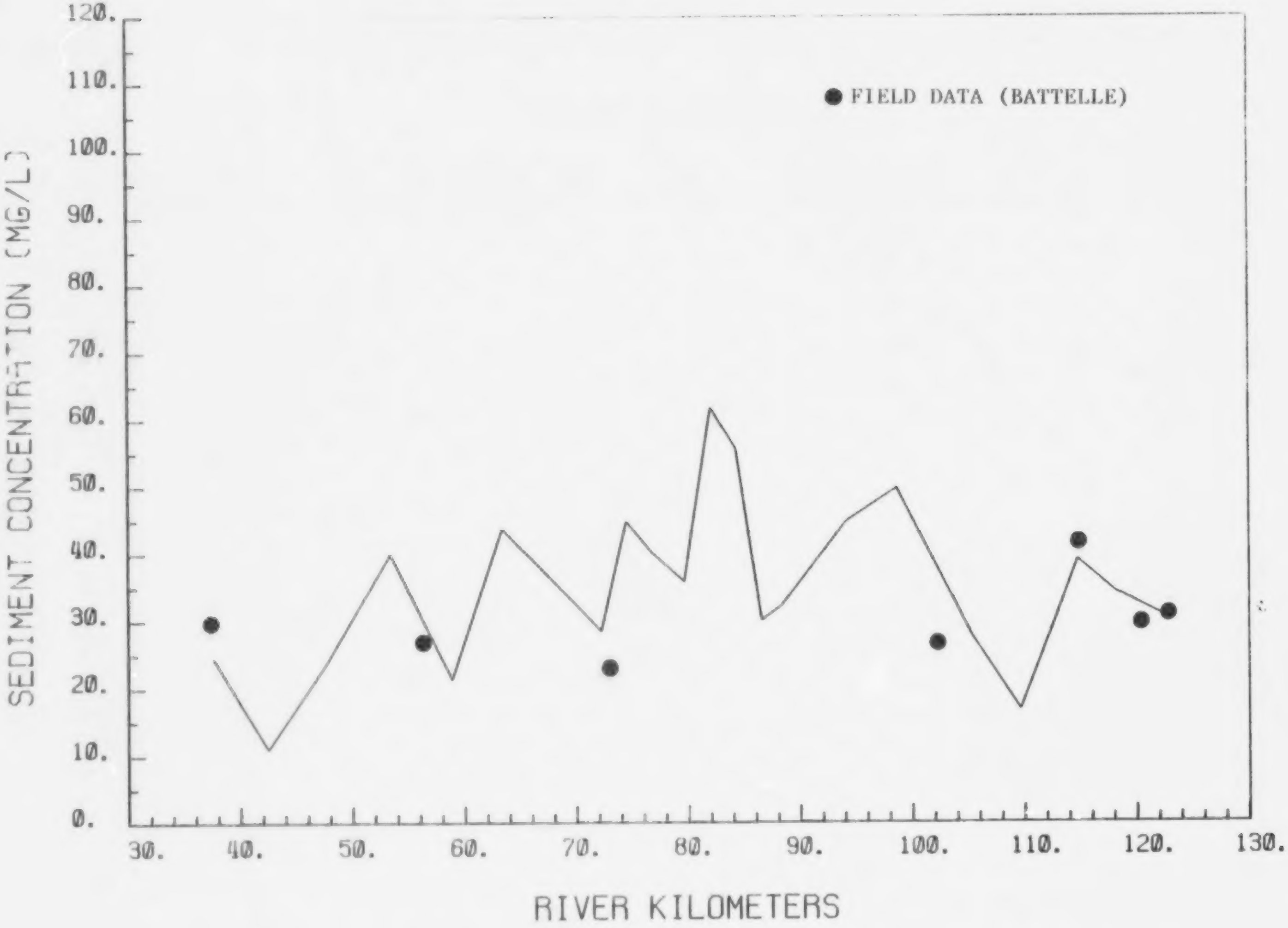


FIGURE VII.31. Longitudinal Distributions of Total Sediment Concentration at the Maximum Ebb Tide for the Fresh-water Discharge of 58.3 m^3/sec, together with Field Data

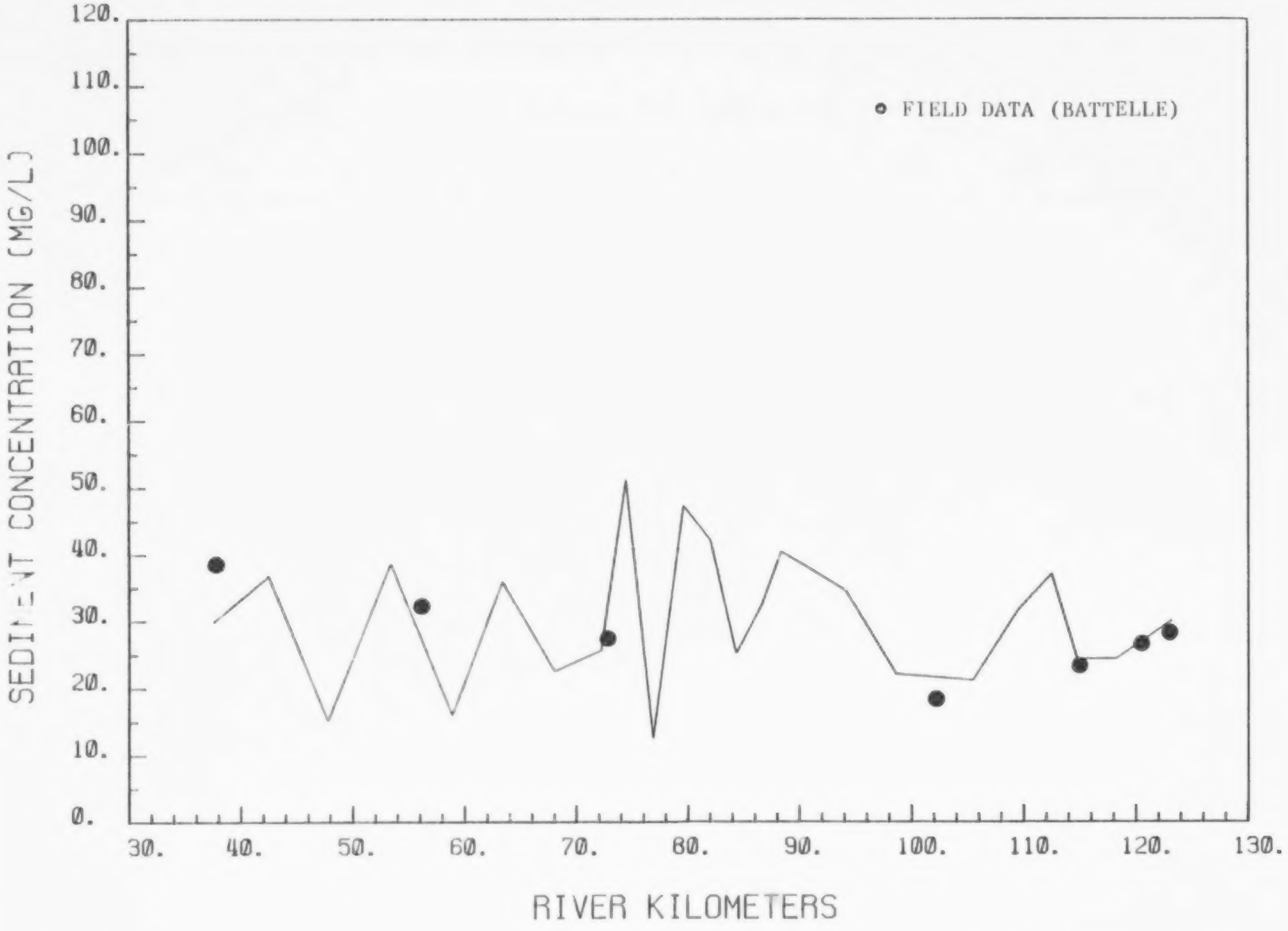


FIGURE VII.32. Longitudinal Distributions of Total Sediment Concentration at the Slack Tide for the Fresh-water Discharge of 58.3 m^3/sec, together with Field Data

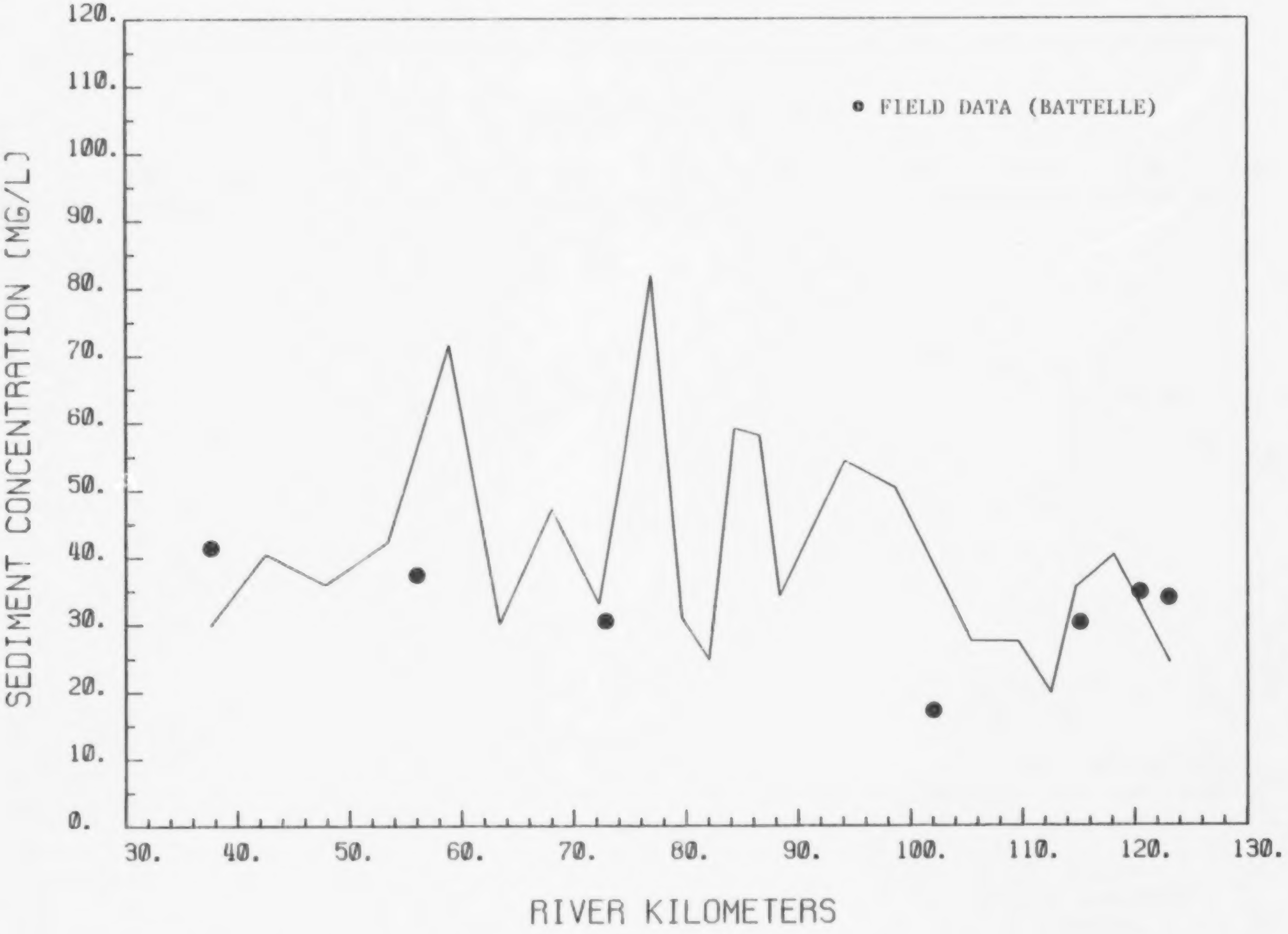


FIGURE VII.33. Longitudinal Distributions of Total Sediment Concentration at the Maximum Flood Tide for the Fresh-water Discharge of 58.3 m^3/sec, together with Field Data

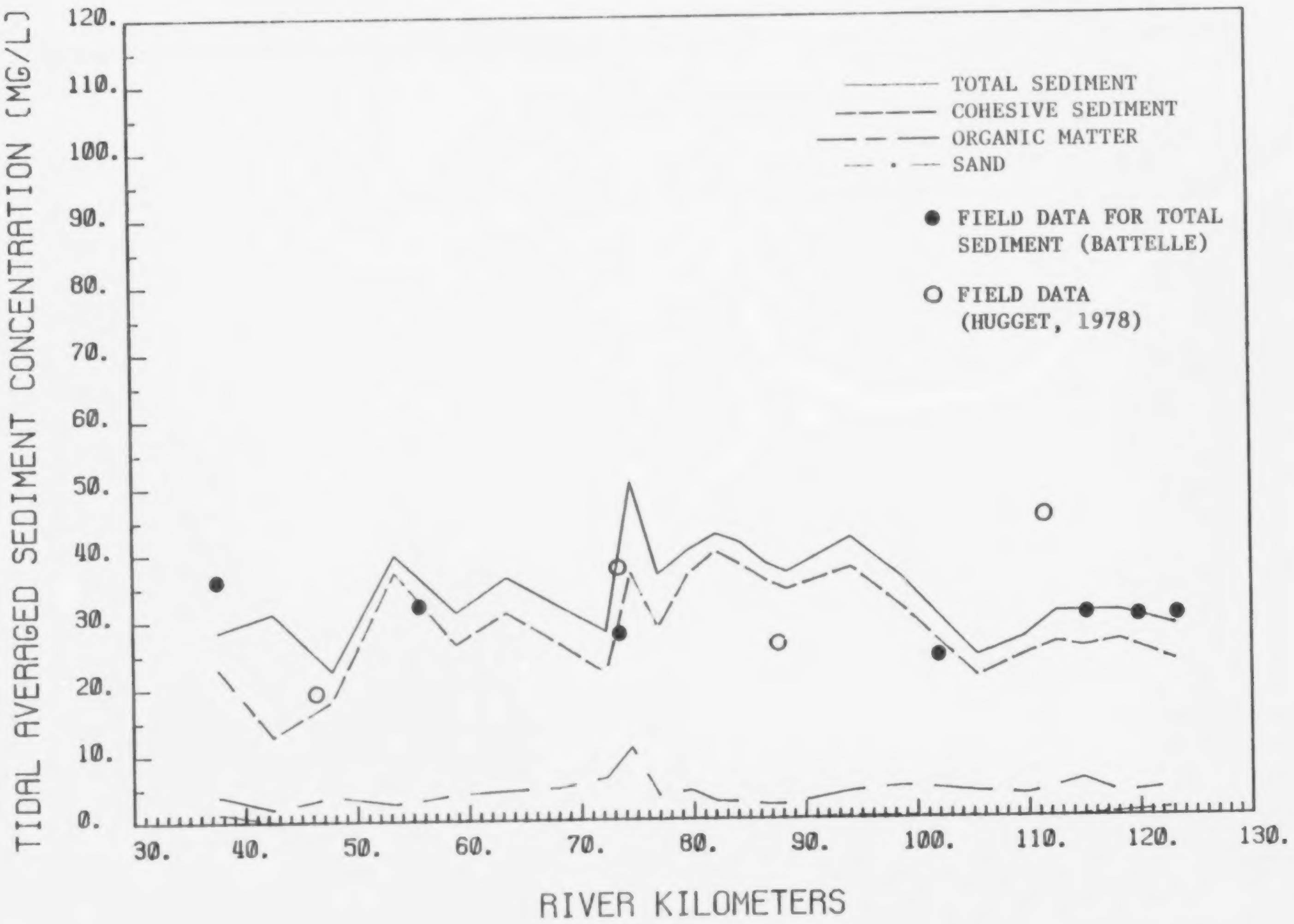


FIGURE VII.34. Tidal Averaged Sediment Concentration of Each Sediment Type for the Freshwater Discharge of 58.3 m^3/sec

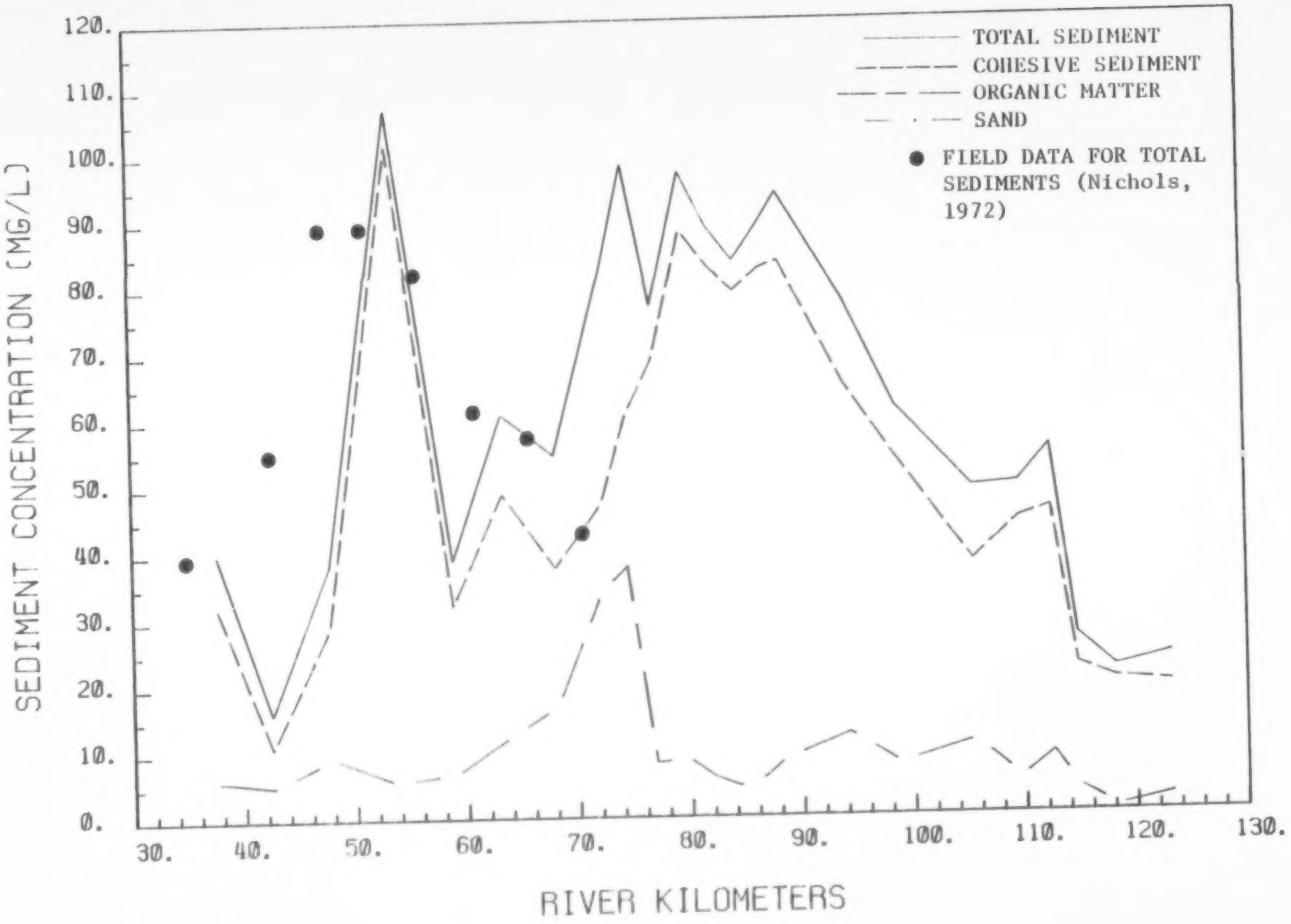


FIGURE VII.35. Longitudinal Distribution of Sediment Concentration of Each Sediment Type at Slack Tide for the Fresh-water Discharge of 247 m^3/sec

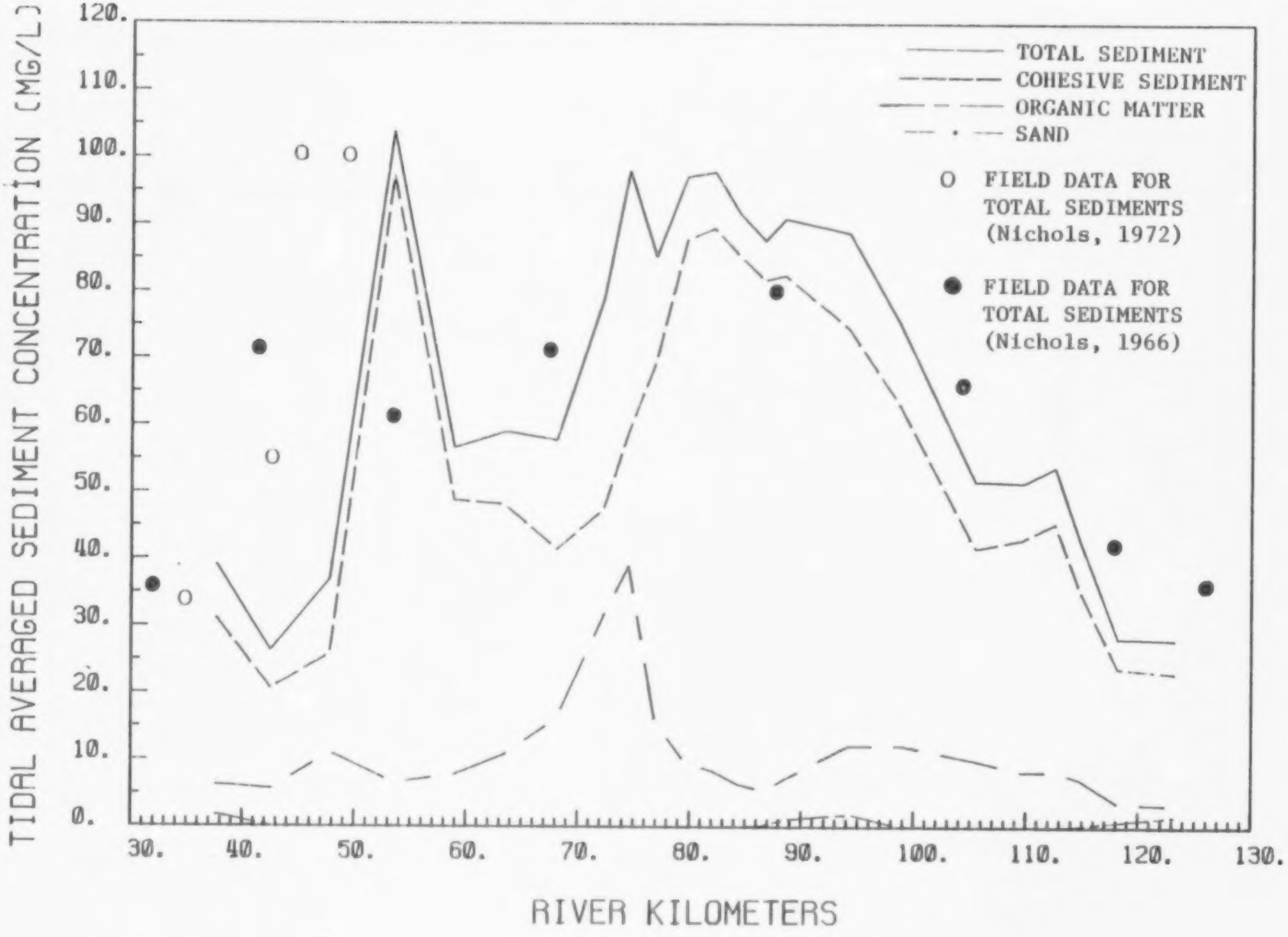


FIGURE VII.36. Tidal Averaged Sediment Concentration of Each Sediment Type for the Freshwater Discharge of 247 m^3/sec

Measured total sediment concentrations in these figures were obtained by Nichols (1972) in March 1965 and March 1960. Field data in 1966 were provided by Nichols through personnel communication. Field data in 1965 were those associated with a fresh-water input discharge of 250 m^3/sec, while 1966 data were obtained in 2 days when the fresh-water input discharge changed from 257 m^3/sec to 144 m^3/sec with the 2-day average discharge of 201 m^3/sec. The present simulation was conducted for the discharge of 247 m^3/sec in this case. Comparison of these field data with computer results at slack tide and tidal average cases (Figures VII.35 and VII.36) indicate excellent agreement among these values. Since the present model was calibrated for the discharge of 58.3 m^3/sec and the model was not readjusted for the 247 m^3/sec case, this excellent agreement with measured data for the latter case provides solid verification of the model.

Verification of the Kepone transport part of the model was conducted by comparing computer results to measured data obtained by Battelle and VIMS for Case 1 (fresh-water discharge of 58.3 m^3/sec). Again Battelle's data were obtained during June 25-28, 1977 and VIMS data were collected during August 24-29, 1977. Since there were no parameters adjustable to fix the computer results to those field data, comparison between them was regarded to be model verification. Figures VII.37 through VII.39 present predicted particulate Kepone concentrations associated with each type of sediment and average particulate Kepone (weighted average of three particulate Kepone values associated with the three sediment types) per unit weight of sediment, together with cross-sectionally averaged field data of average particulate Kepone concentrations obtained by Battelle, for maximum ebb, slack and maximum flood tides, respectively.

Figures VII.40 and VII.41 present predicted tidal averaged particulate Kepone concentrations per unit weight of sediment, and those per unit volume of water, respectively, together with measured average particulate Kepone concentrations obtained by Battelle and VIMS. As noted above, Battelle's data in these figures are cross-sectionally averaged values. However, VIMS data are those measured in a main navigation channel of the River. Except for the maximum flood tide case (Figure VII.39), the agreement between the computer results and the field data are good. For example, Figure VII.41 reveals excellent agreement except one measured point at River Kilometer 111. The discrepancy between the predicted and measured value at River Kilometer 111 may be explained as follows: in the upper most part of the River, suspended and dissolved Kepone distribution across the River is much less uniform, as compared to distributions in the lower part because of the short distance from the original Kepone discharge source (Bailey Creek). Hence, VIMS measured data obtained in a main channel of the River at River Kilometer 111 are expected to be higher than a cross-sectional average there. However, in the lower part of the River, the measured data in the main channel may be much closer to the cross-sectional average. This trend may be reflected in Figure VII.41, when the computed and measured values are compared. From the comparisons shown in Figures VII.37 through VII.41, it is judged that the particulate Kepone transport part of the model has been verified with sufficient field data.

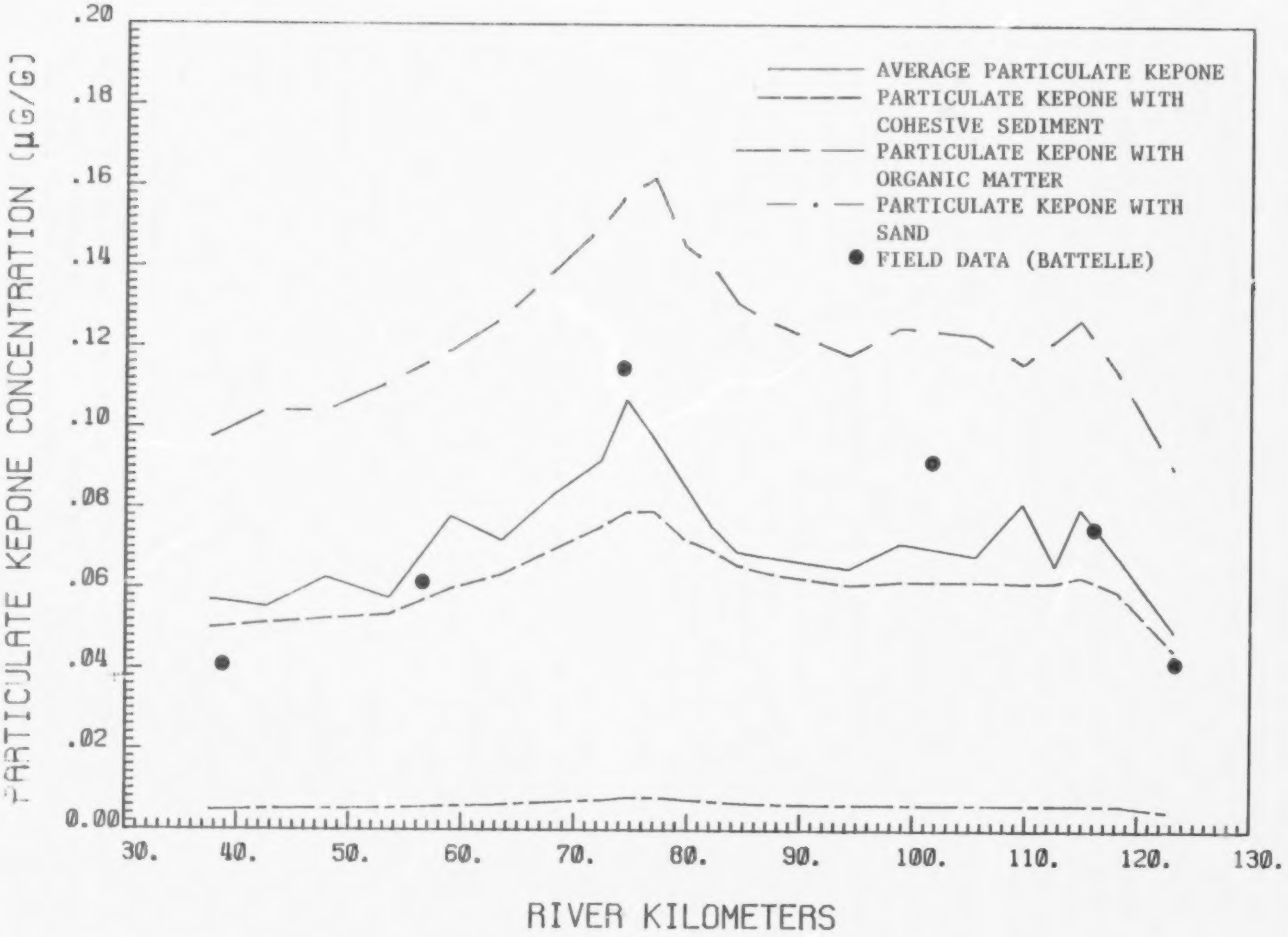


FIGURE VII.37. Longitudinal Distributions of Particulate Kepone Concentrations at Maximum Ebb Tide for the Fresh-water Discharge to 58.3 m^3/sec

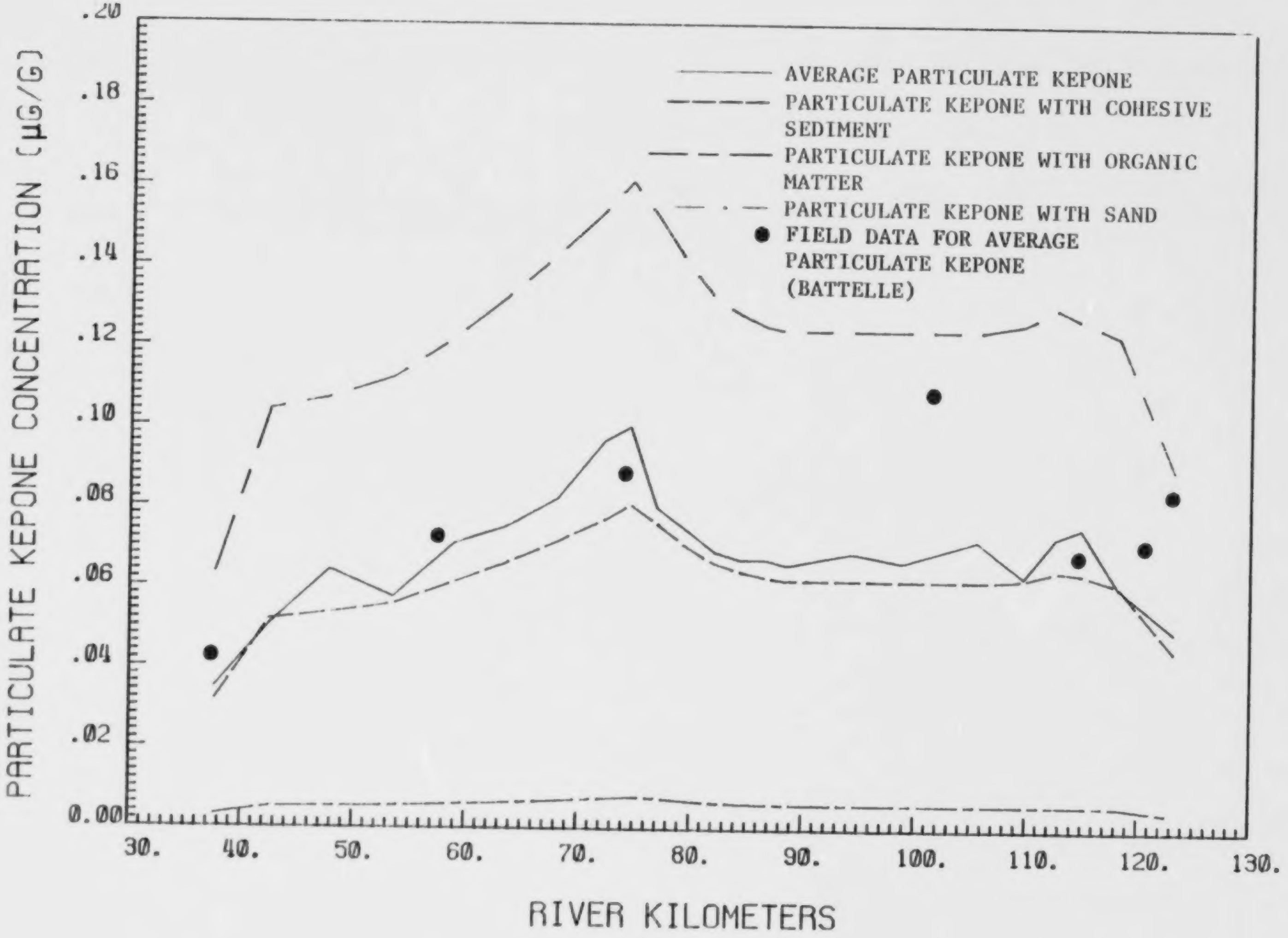


FIGURE VII.38. Longitudinal Distributions of Particulate Kepone Concentrations at Slack Tide for the Fresh-water Discharge of 58.3 m^3/sec

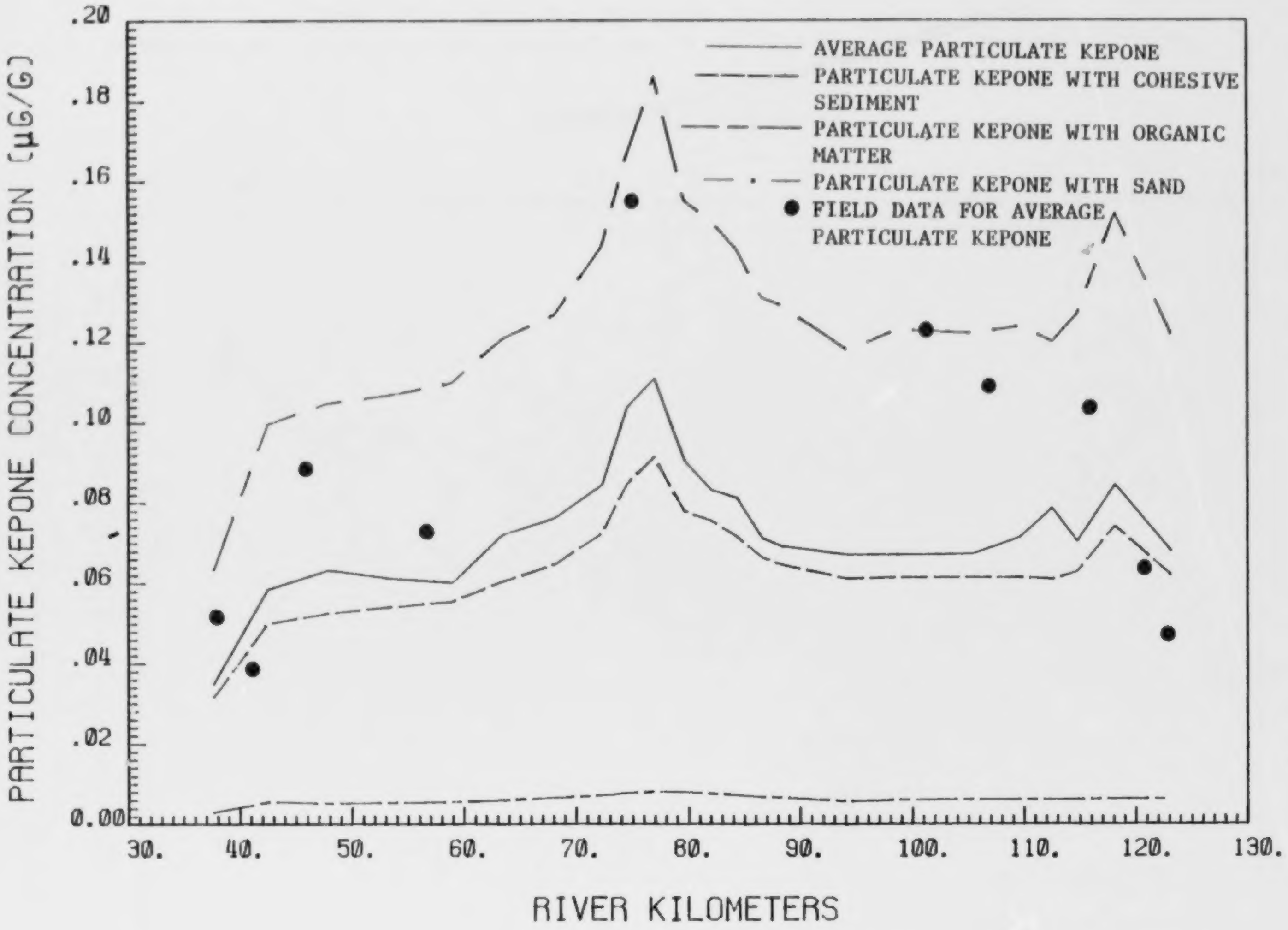


FIGURE VII.39. Longitudinal Distributions of Particulate Kepone Concentrations at Maximum Flood Tide for the Fresh-water Discharge of 58.3 m^3/sec

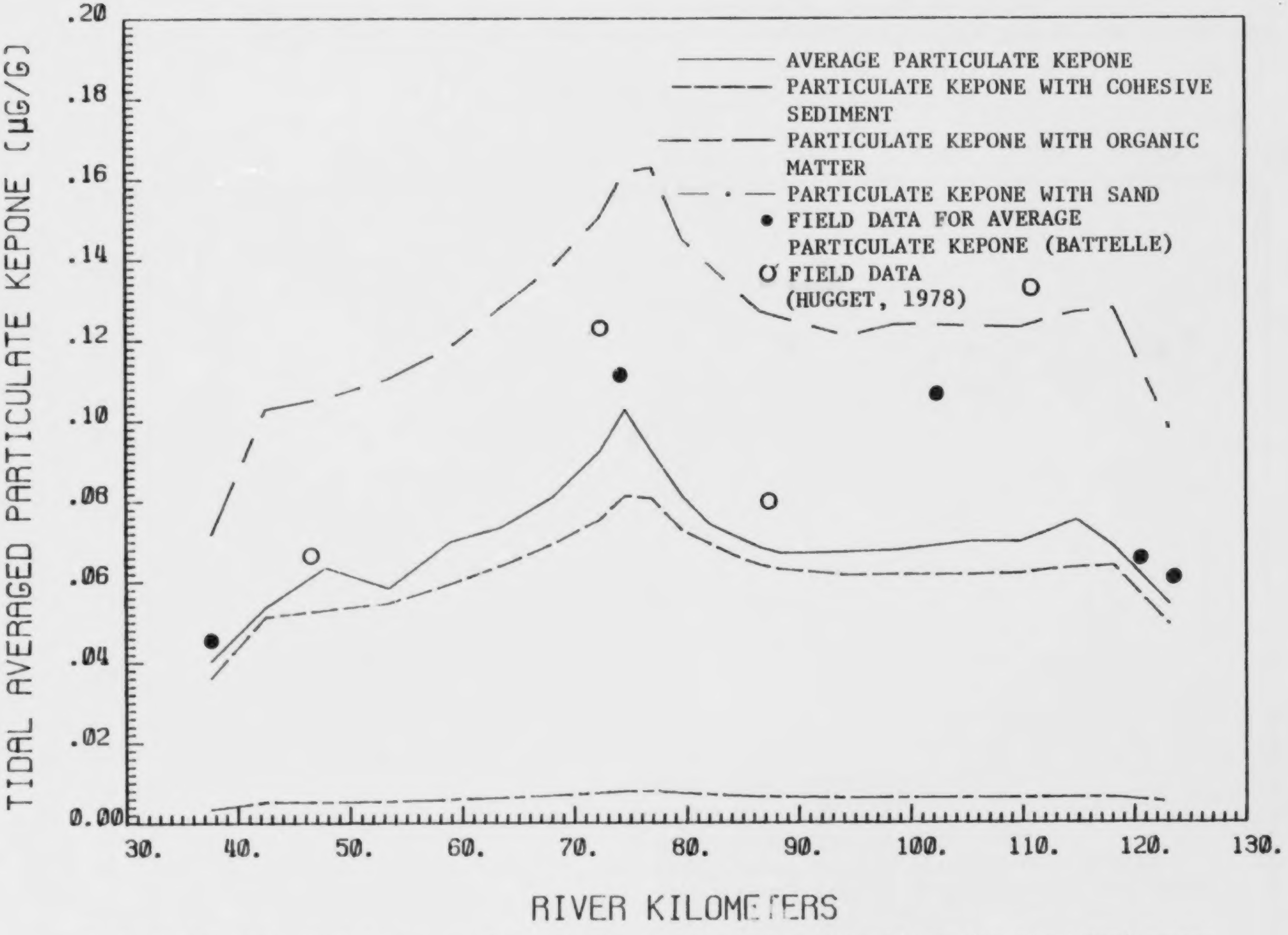


FIGURE VII.40. Tidal Averaged Particulate Kepone Concentrations for the Fresh-water Discharge of 58.3 m^3/sec

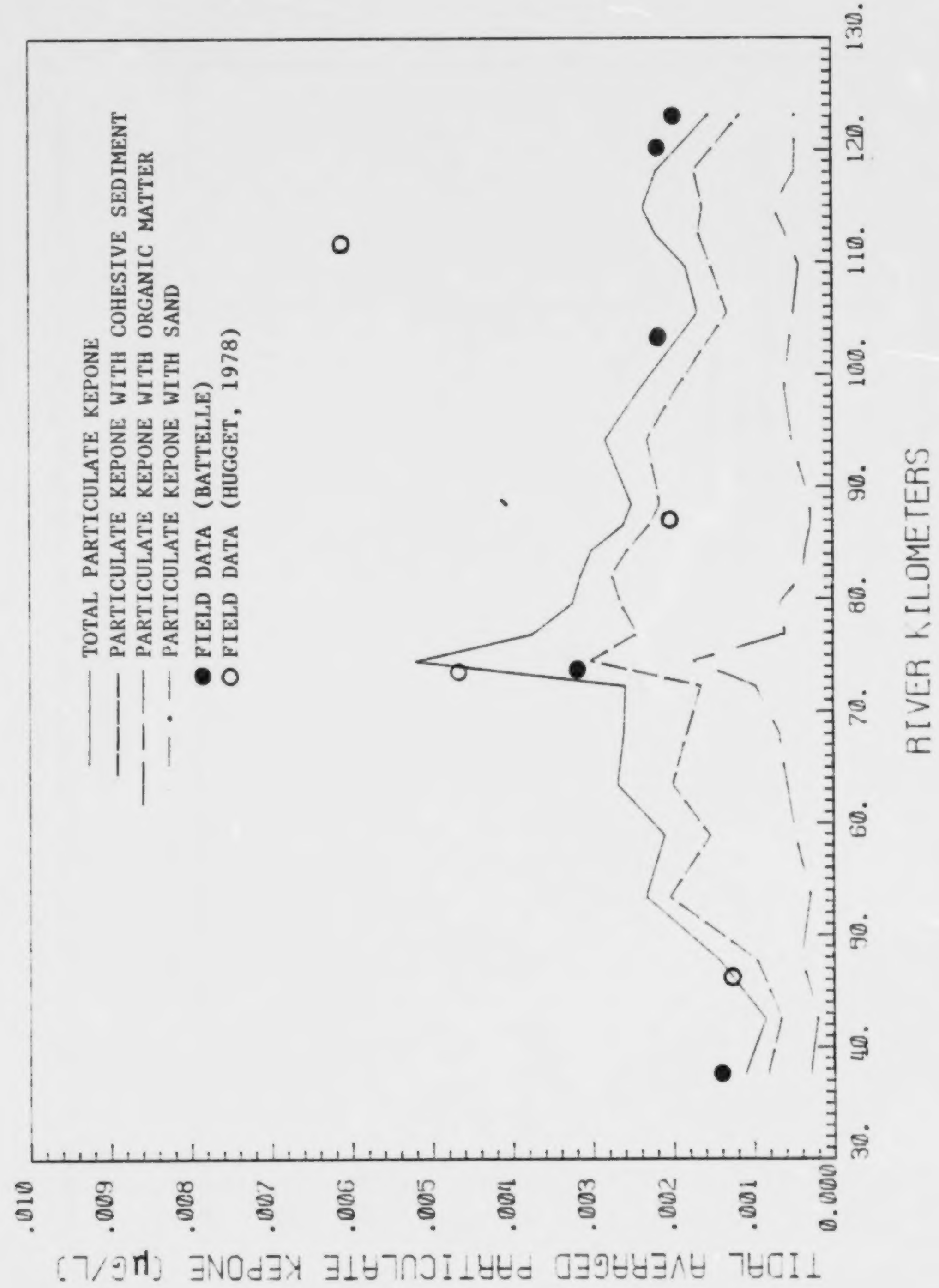


FIGURE VII.41. Longitudinal Distributions of Tidal Averaged Particulate Kepone Concentrations per Unit Volume of Water for the Fresh-water Discharge of 58.3 m^3/sec

As shown in Tables VII.1 through VII.10, most of dissolved concentrations that occurred in the James River study reach were below the detection limit which is approximately 0.005 to 0.010 μg/ℓ. VIMS also reported from their August 1977 field sampling that the dissolved Kepone level in the James River is below the detection limit. Hence in this study, dissolved concentrations at both ends of the study reach were set to 0.007 μg/ℓ, which is approximately the highest possible value maintained in the River. Figure VII.42 shows the computed tidal averaged dissolved Kepone concentration together with particulate and total (sum of dissolved and particulate) Kepone concentrations. This figure indicates that dissolved Kepone concentrations vary from approximately 0.0048 to 0.0080 μg/ℓ. As stated above, from the measured particulate Kepone concentration and the K_d value, expected dissolved Kepone concentration is somewhat below the detection limit but is roughly the same order of magnitude to the detection limit. Hence, the predicted level of dissolved concentration by the FETRA code is the highest possible value found in the study area but still below the detection limit. From these considerations, the dissolved Kepone transport part of the FETRA code was also judged to be reasonably well verified with available information on dissolved Kepone concentrations in the tidal James River. Prediction of a total Kepone concentration (sum of dissolved and particulate Kepone concentrations) is then considered to be verified. Since measured values were generally below detection limits for dissolved Kepone, estimates will be on the high side.

Although it is desirable to obtain additional sets of field data to further verify the FETRA code, it is very expensive and time consuming to obtain a large number of field data. As discussed at the mathematical model workshop (Oak Ridge National Laboratory, 1978), most simulation models have been applied to some field cases but have never been verified. In light of these situations, it is considered that available field and laboratory data under this study will suffice to judge the validity of the mathematical simulation model, FETRA. As noted earlier, estimates may be high due to use of dissolved Kepone data at the level of detection.

Summary of Computer Simulation Results on Kepone Transport--

Only the most pertinent results of Kepone migration are discussed in this section. Further detailed simulation results are discussed in Appendix M.

Case 1 - Net Fresh-water Discharge of 58.3 m^3/sec--Figure VII.40, as shown before, presents predicted tidally averaged longitudinal particulate Kepone distributions associated with each type of sediment and average particulate Kepone (weighted average of three particulate Kepone values associated with the three sediment types) per unit weight of sediment, together with the the field data. The mathematical simulation results indicate that the particulate Kepone concentration generally increases from 0.05 μg/g to 0.105 μg/g with movement seaward from City Point (River Kilometer 123) to the confluence of the James River and the Chickahominy River (River Kilometer 77) with an intermediate peak around Bailey Bay and Jordan Point (River Kilometer 118). Seaward from the James-Chickahominy River confluence, the particulate Kepone concentration decreases gradually and has a value of approximately 0.04 μg/g in Burwell Bay (River Kilometer 37.6).

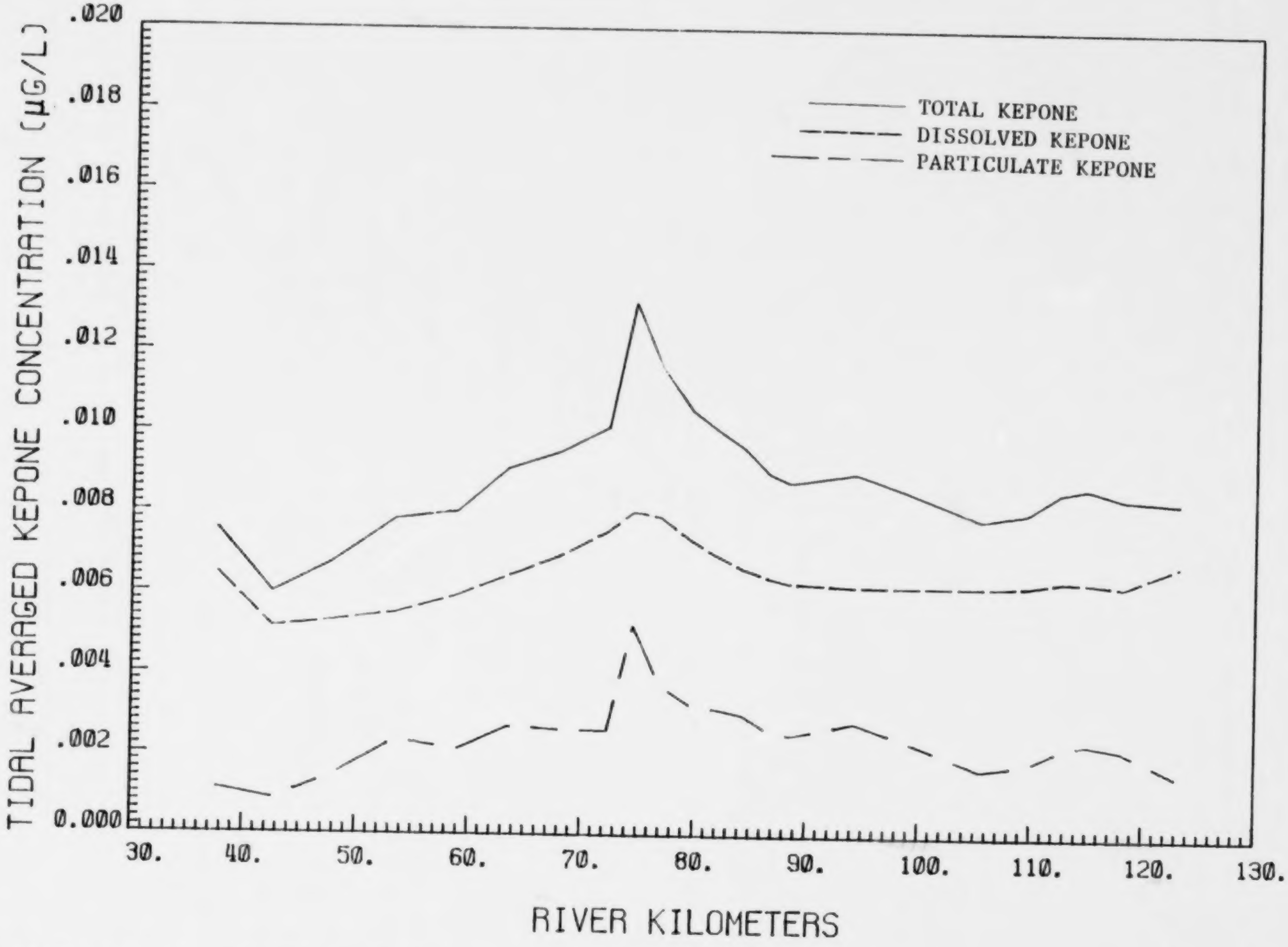


FIGURE VII.42. Longitudinal Distributions of Tidal Averaged Total, Dissolved and Particulate Kepone Concentrations for the Fresh-water Discharge of 58.3 m^3/sec

This figure also reveals that the Kepone concentration associated with the organic material is approximately twice as high as the concentration associated with cohesive sediment, which in turn has a Kepone concentration 10 times higher than that of sand. Areawide averages for particulate Kepone adsorbed by the cohesive sediment, organic matter and sand are 0.063, 0.126, and 0.006 μg/g, respectively. The total particulate Kepone concentration averaged over the 86-km reach is 0.071 μg/g.

Figure VII.41 presents tidally averaged longitudinal variations of dissolved, particulate and total (sum of dissolved and particulate) Kepone concentrations. This figure reveals that total Kepone concentrations vary from approximately 0.006 μg/ℓ to 0.0132 μg/ℓ with the peak concentration occurring at River Kilometer 75 (in the vicinity of the Swann Point). Concentrations of dissolved, particulate and total Kepone average over the 86-km reach are 0.0065, 0.0024, and 0.089 μg/ℓ. These values indicate that approximately 27% of total Kepone is carried by sediment, while 73% remains in the dissolved form.

The mathematical simulation results also reveal that at Burwell Bay, the tidally averaged total Kepone concentration is 0.0076 μg/ℓ and that approximately 14.0 kg of Kepone per year are transported from the tidal James River towards Chesapeake Bay. Dissolved and particulate Kepone concentrations are 0.0064 μg/ℓ and 0.0012 μg/ℓ, respectively. Hence, suspended sediment carries approximately 2.2 kg Kepone per year seaward from the tidal James River, while 11.8 kg of Kepone are transported into the ocean and Chesapeake Bay per year in a dissolved form. Since there is some possible deposition of contaminated sediment and adsorption of dissolved Kepone by cleaner suspended sediment between Burwell Bay and the river mouth, 14.0 kg/yr is a somewhat conservative estimate.

Accumulated bed elevation changes after 1-month simulation are shown in Figure VII.43. In this figure, positive values along the vertical axis indicate the amount of sediment deposition in mm, during a 1-month simulation, while negative values show the amount of river bed scoured during the same period. This figure reveals a series of scouring and deposition patterns reflecting the complex geometry of the tidal James River with many bays being connected by narrow channels. For this flow case, an average annual net bed deposition rate for the 86-km tidal James River reach is predicted to be approximately 1.7 mm/yr.

Figure VII.44 shows the change in bed surface Kepone concentration that occurred during a 1-month simulation. The Kepone concentrations shown here are those which appeared on the very surface of the river bed without any mixing with Kepone existing below that level. For example, in Bailey Bay (around River Kilometer 120) Kepone concentration is reduced dramatically during a 1-month simulation. As shown in Figure VII.43, Bailey Bay experienced sediment deposition of approximately 2 mm. Figure VII.44 indicates that the Kepone concentration in this top 2-mm layer is reduced from the level shown in the solid line to those shown in the dotted line. Another example

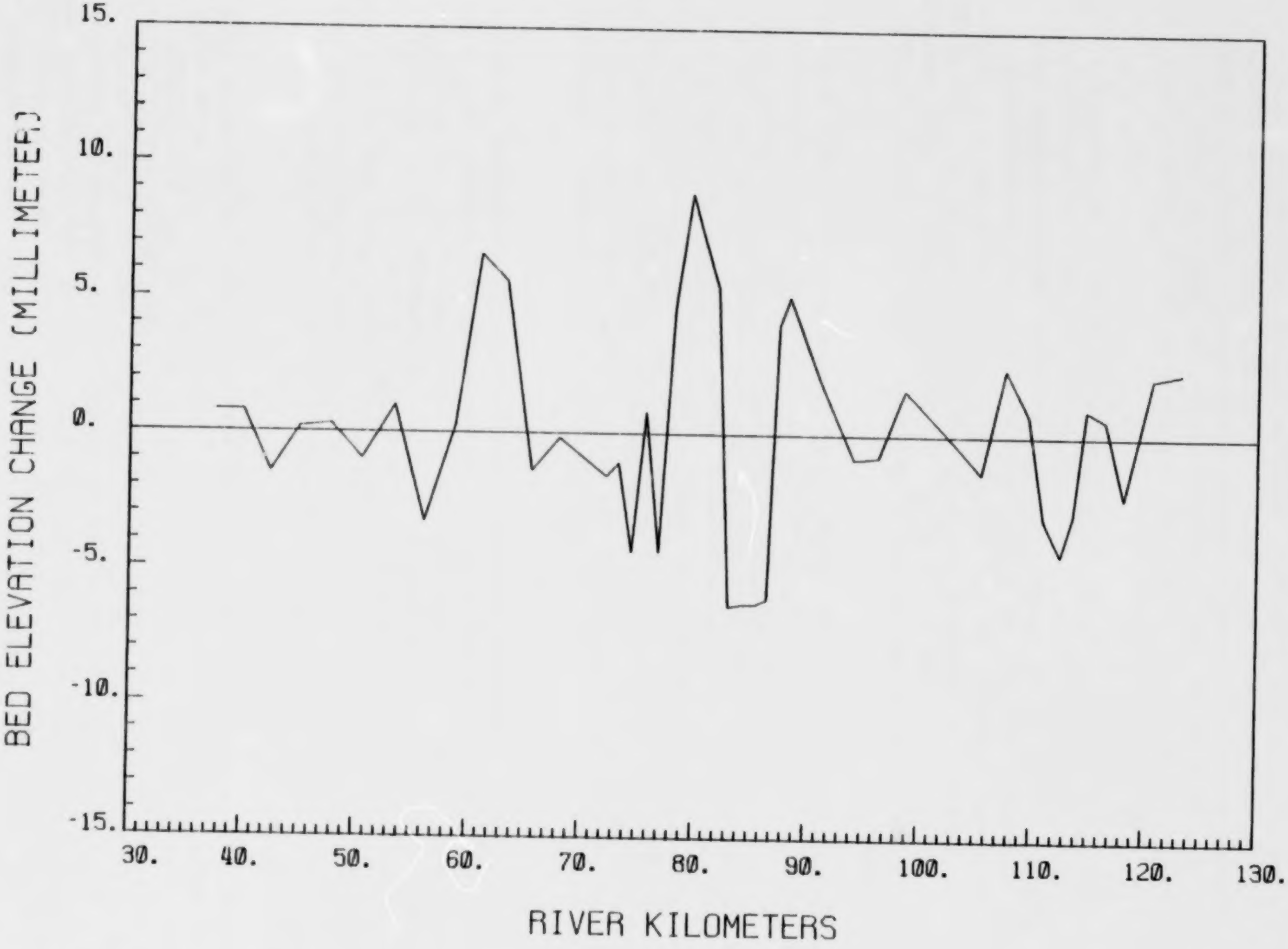


FIGURE VII.43. Variation of River Bed Elevation Changes Due to Sediment Deposition and/or Bed Scouring at Maximum Ebb Tide for the Fresh-water Discharge of 58.3 m^3/sec

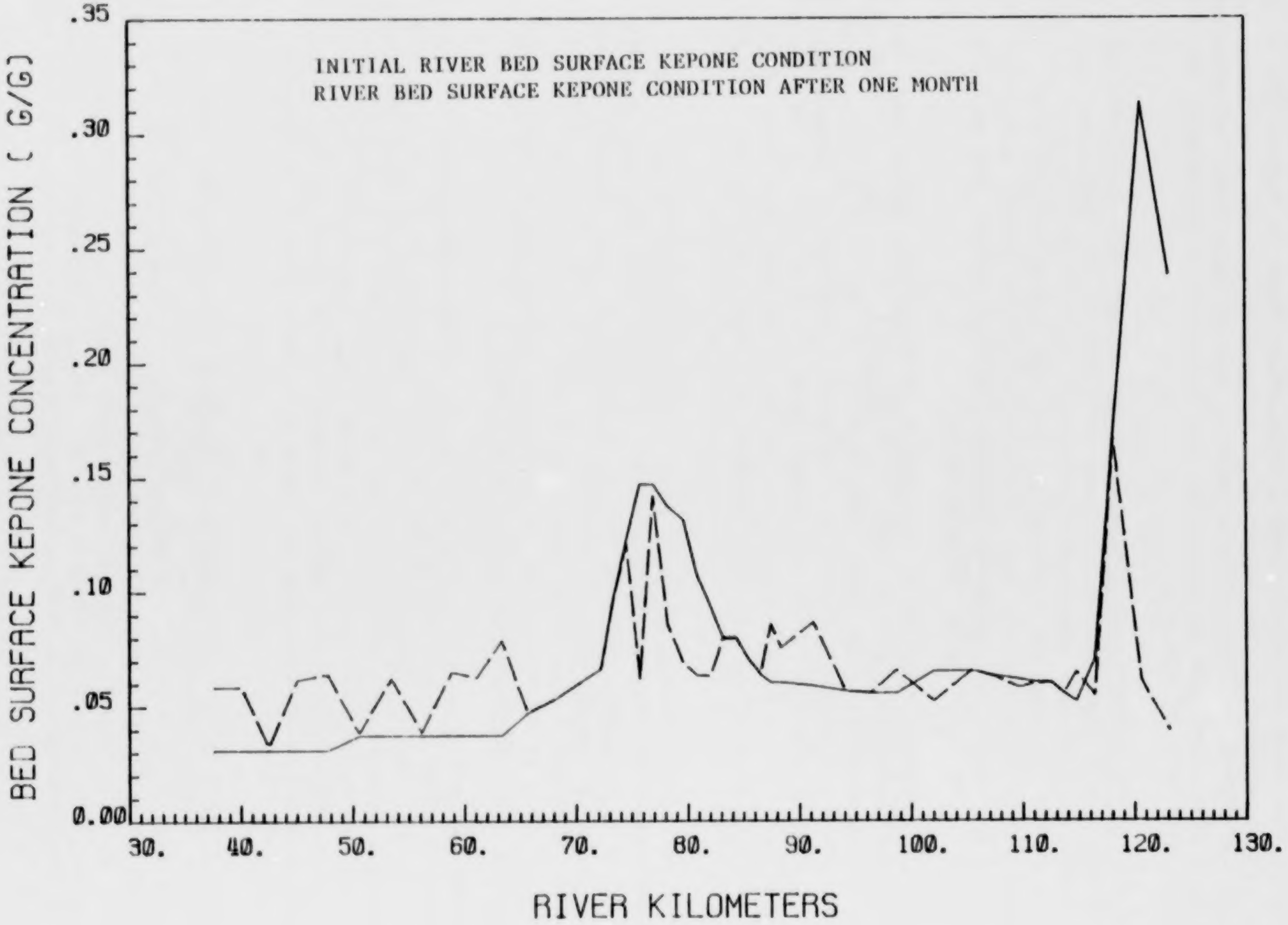


FIGURE VII.44. Change on Bed Surface Kepone Concentration Occurred During 1-Month Simulation for the Fresh-water Discharge of 58.3 m^3/sec

occurs in the 70-River Kilometer area. Figure VII.43 reveals that there is a net scour of approximately 1 mm. Hence the Kepone concentration in the very surface of the river bed after 1-month simulation shown in Figure VII.44 is the one which appeared in the layer as it originally existed 1 mm below the original bed surface. Figure VII.44 reveals the definite trend of reducing the Kepone level near the upper part of the river and of increasing the level near the lower part of the River.

Case 2 - Net Fresh-water Discharge of 247 m^3/sec--The tidal averaged particulate Kepone distribution as shown in Figure VII.45 indicates that the total particulate Kepone concentration changes from 0.040 μg/g to 0.098 μg/g with the overall average of 0.070 μg/g. The peak concentration occurs at approximately River Kilometer 75. Overall particulate Kepone concentrations associated with suspended cohesive sediment, organic matter and sand are 0.060, 0.120, and 0.006 μg/g, respectively.

Tidal averaged longitudinal variations of dissolved, particulate and total Kepone concentrations are shown in Figure VII.46. Tidal averaged total Kepone concentration varies from 0.0068 μg/ℓ to 0.0166 μg/ℓ with two peaks at River Kilometer 75 (near Swann Point) and River Kilometer 53 (around the null zone for this fresh-water input discharge case). Concentrations of dissolved, particulate and total Kepone averaged over the study area are 0.006 μg/ℓ, 0.0048 μg/ℓ and 0.0108 μg/ℓ. This implies that approximately 44% is carried by the sediment, while 56% of Kepone is in a dissolved form.

The present mathematical study also indicates that at Burwell Bay, the tidal averaged total Kepone concentration is 0.0080 μg/ℓ and that approximately 62.3 kg of Kepone per year are discharged out from the tidal James River towards Chesapeake Bay. Dissolved and particulate Kepone concentrations are estimated to be 0.0064 μg/ℓ and 0.0016 μg/ℓ. These values imply that out of 62.3 kg of total Kepone, 12.5 kg of Kepone are transported by sediment and 49.8 kg of Kepone are in a dissolved form.

Accumulated bed elevation changes due to sediment deposition and river bed scouring after 1-month simulation are shown in Figure VII.47. As shown in this figure, bays in general have sediment deposition and narrow connecting channels between bays experience bed scouring. For this case an average annual net bed deposition rate for the 86-km tidal James River reach is predicted to be approximately 3.6 mm/yr. Figure VII.48 indicates the change in bed surface Kepone concentration and reveals a trend similar to that for Case 1 (Figure VII.44).

Case 3 - Net Fresh-water Discharge of 681 m^3/sec--The tidal averaged particulate Kepone concentrations are shown in Figure VII.49. The figure indicates that total particulate Kepone changes its concentrations from 0.045 μg/g to 0.095 μg/g and has three peaks, one each at River Kilometer 43, 75, and 118. Tidal averaged total particulate Kepone over the 86-km reach is 0.076 μg/g. Particulate Kepone adsorbed by cohesive sediment, organic material and sand averaged over the entire study reach is 0.064 μg/g, 0.129 μg/g and 0.006 μg/g, respectively.

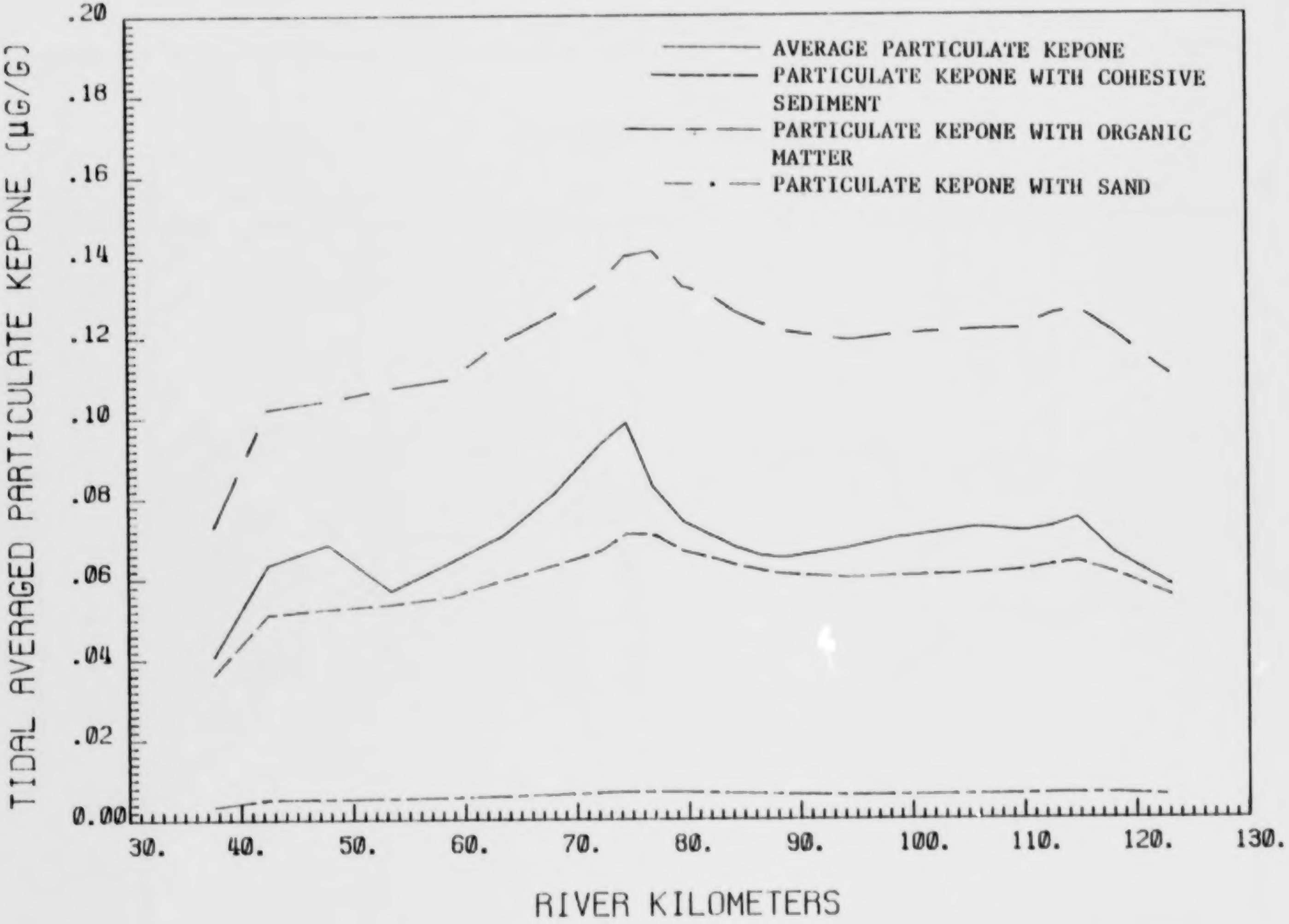


FIGURE VII.45. Tidal Averaged Particulate Kepone Concentrations for the Fresh-water Discharge of 247 m^3/sec

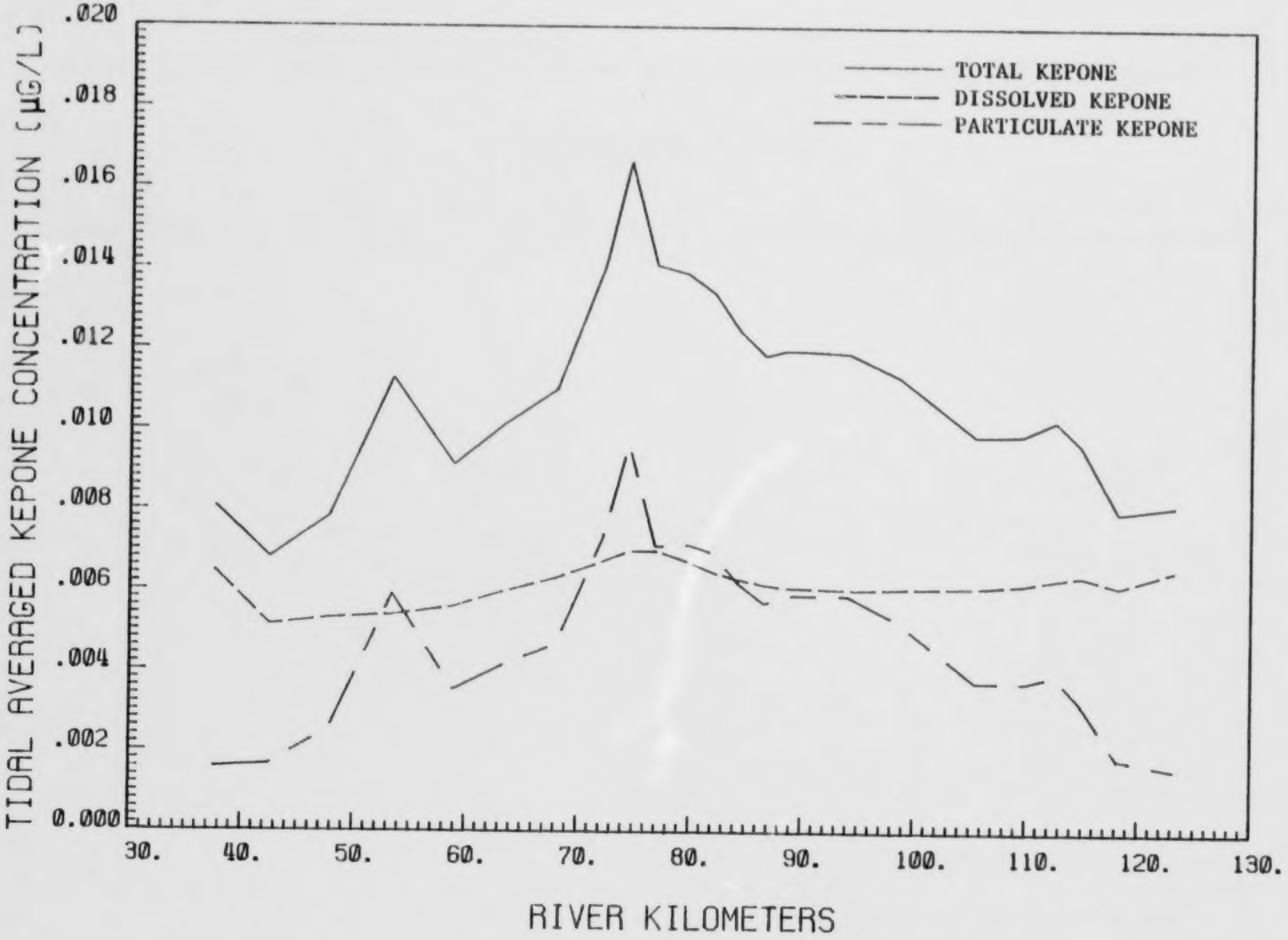


FIGURE VII.46. Longitudinal Distributions of Tidal Averaged Total, Dissolved and Particulate Kepone Concentrations for the Fresh-water Discharge of 247 m^3/sec

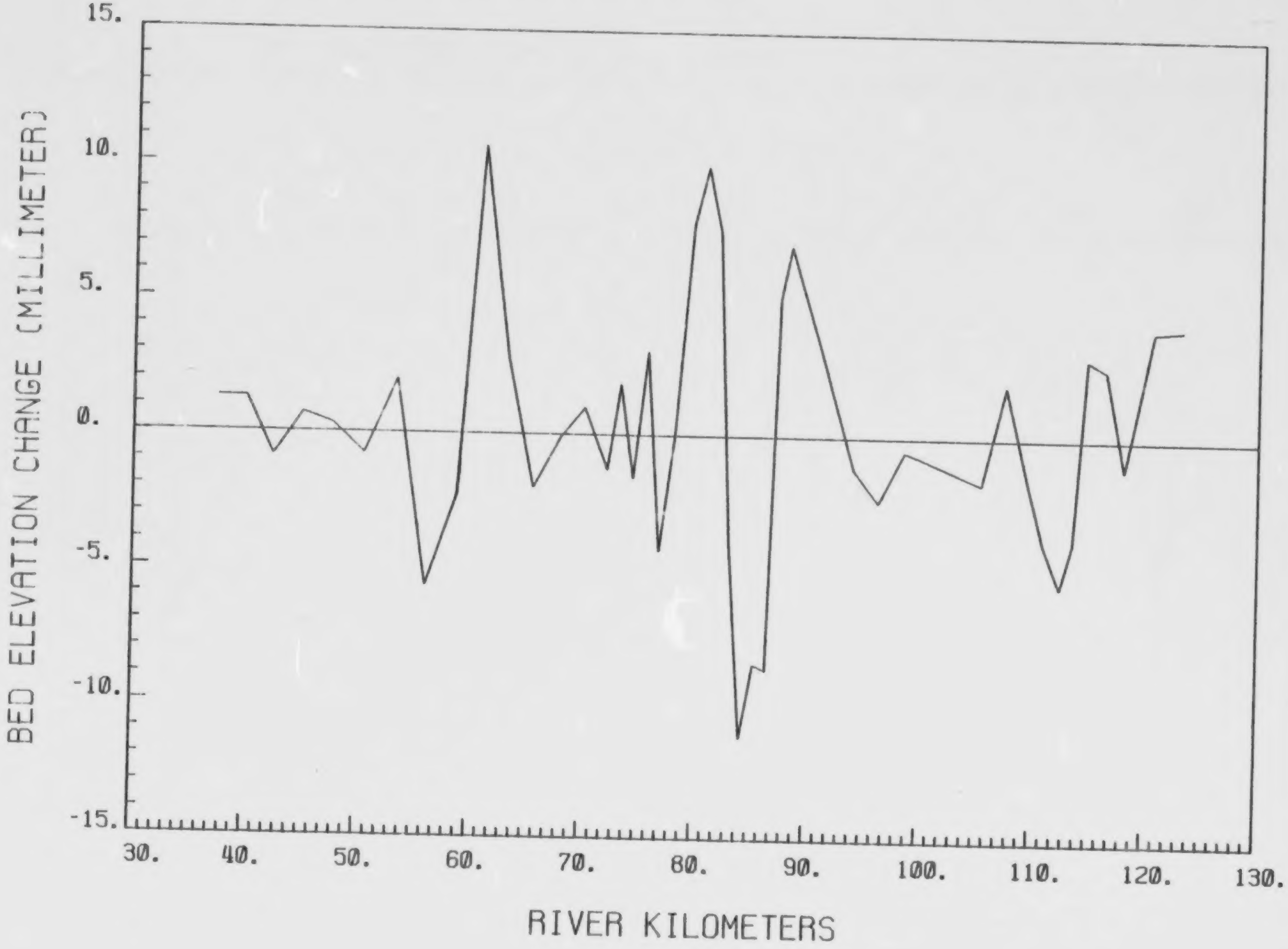


FIGURE VII.47. Variation of River Bed Elevation Changes Due to Sediment Deposition and/or Bed Scouring at Maximum Ebb Tide for the Fresh-water Discharge of 247 m^3/sec

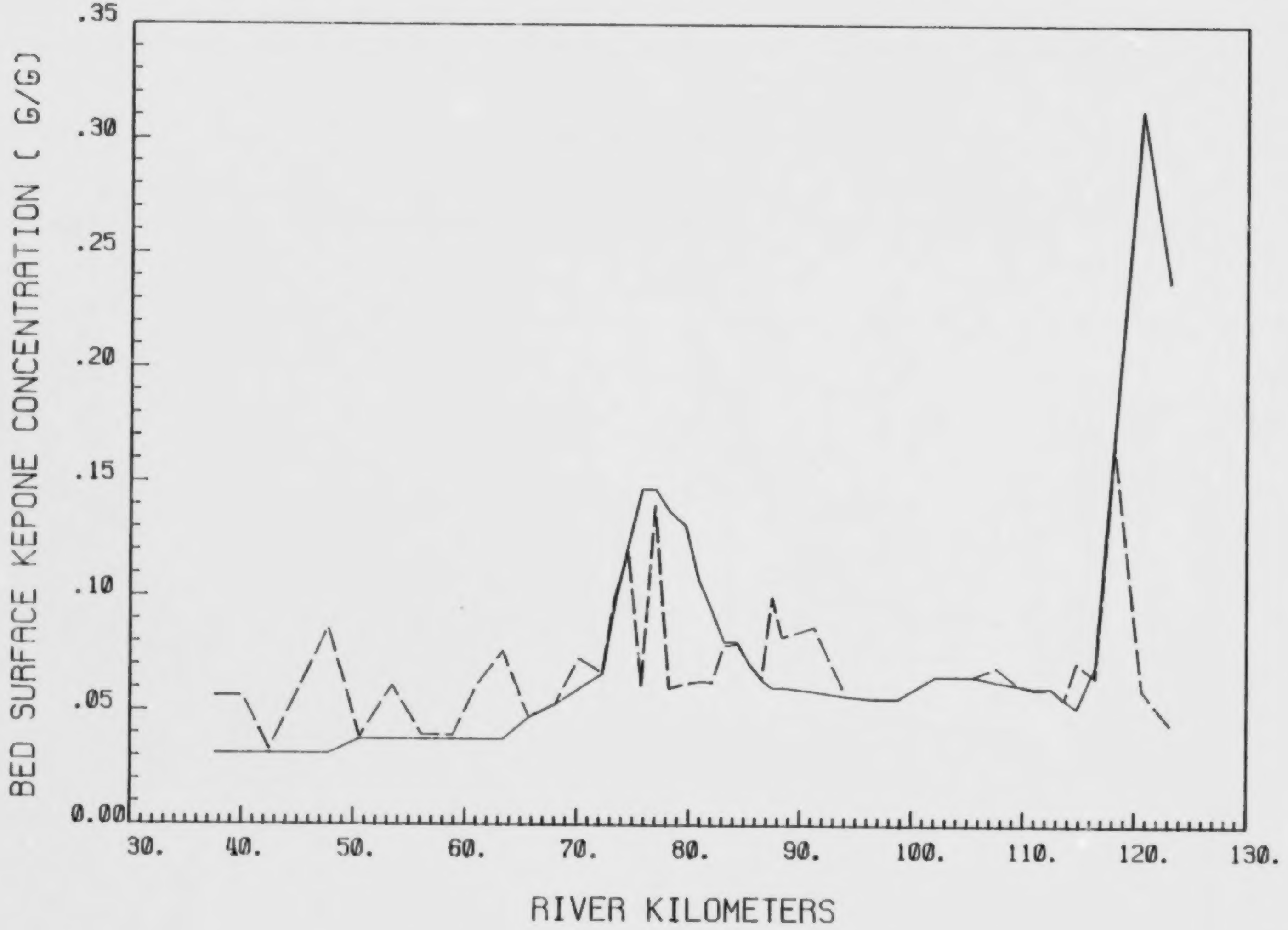


FIGURE VII.48. Change in Bed Surface Kepone Concentration Occurred During 1-Month Simulation for the Fresh-water Discharge of 247 m^3/sec

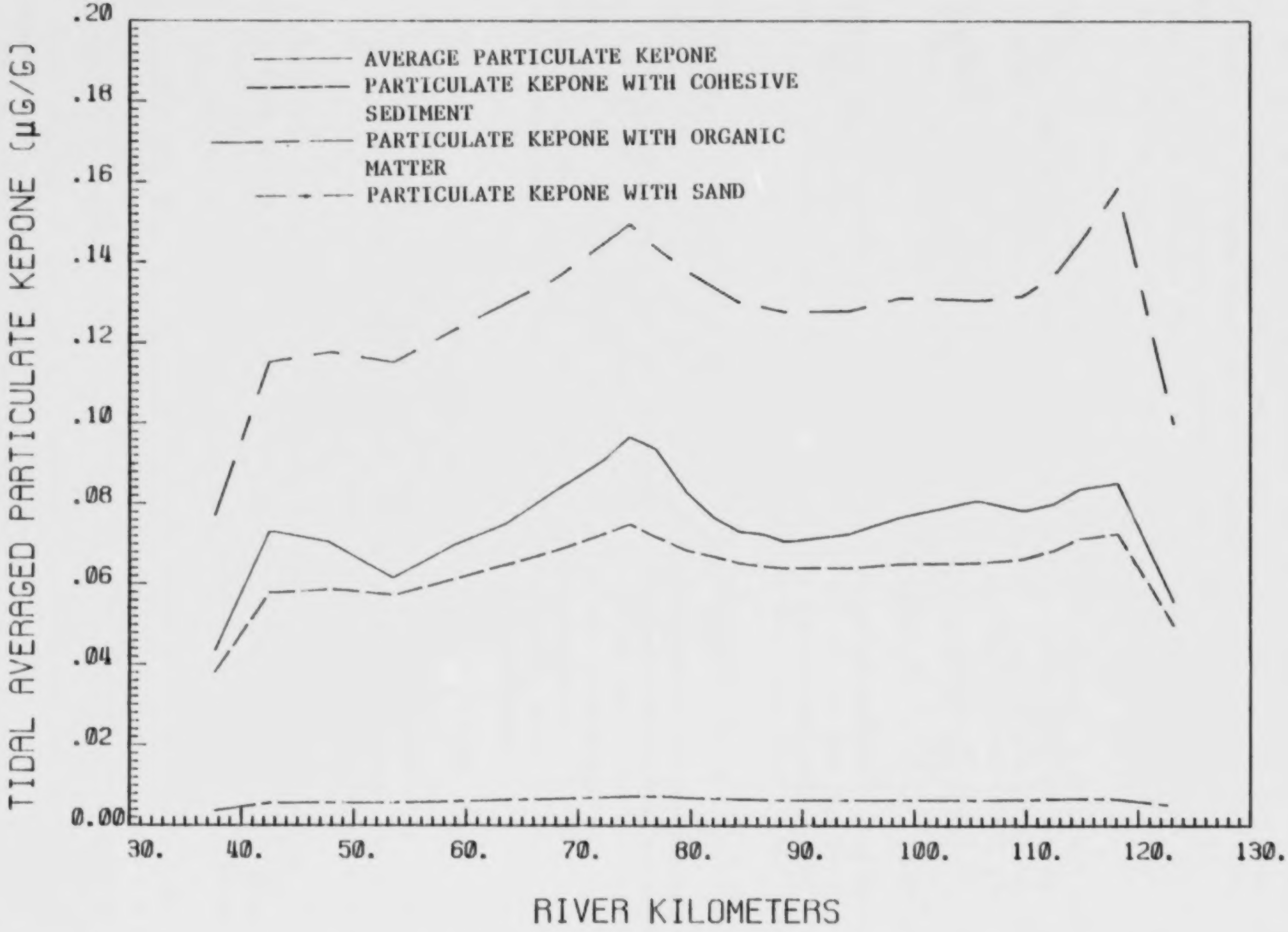


FIGURE VII.49. Tidal Averaged Particulate Kepone Concentrations for the Fresh-water Discharge of 681 m^3/sec

As shown in Figure VII.50, tidal averaged total Kepone concentration varies from 0.0072 μg/ℓ to 0.0155 μg/ℓ with an average value of 0.0124 μg/ℓ. Tidal averaged particulate Kepone concentration obtained over the entire 86-km reach is 0.00575 μg/ℓ which corresponds to 46% of the total Kepone concentration. Similarly, overall dissolved Kepone concentration is 0.00665 μg/ℓ which is 54% of the total Kepone concentration. As compared to Cases 1 and 2, particulate Kepone for this case has the highest contribution to the total Kepone, due to the higher rate of bed scouring and subsequent sediment concentration under this flow condition.

The simulation results also reveal that at Burwell Bay, the tidal averaged concentrations of total particulate and dissolved Kepone are 0.0093 μg/ℓ, 0.0026 μg/ℓ, and 0.0066 μg/ℓ, respectively. Hence, it is estimated that under this fresh-water discharge of 681 m^3/sec, approximately 200 kg of Kepone per year are flushed out from the tidal James River toward Chesapeake Bay. Of that total, 28% or 56.0 kg is being transported by sediment and 72% or 144 kg is moved out in a dissolved form.

Changes in accumulated river bed elevation and in Kepone concentration in the river bed surface are shown in Figures VII.51 and VII.52. Unlike Cases 1 and 2, the overall net erosion of the river bed occurs at a rate of 4.1 mm/yr under this high flow condition.

Case 4 - Overall Evaluation Through Combination of Results from Cases 1, 2, and 3--In order to obtain a realistic estimate of Kepone transport, the computer results obtained from Cases 1, 2, and 3 were combined with their frequency of occurrence. As mentioned before, fresh-water discharges of 58.3 m^3/sec (Case 1) and 681 m^3/sec (Case 3) correspond to the 10 and 90 percentile of the discharge. The discharge of 247 m^3/sec (Case 2) is the annual average discharge. To best estimate probable annual Kepone transport, based on the results of these three cases, Cases 1, 2, and 3 were assigned to occur 30, 40 and 30% of the time.

The annual total Kepone concentration over the area is estimated to be 0.0108 μg/ℓ. The annual particulate Kepone concentration over the area is computed to be 0.072 μg/g or 0.0028 μg/ℓ, while dissolved Kepone concentration is 0.0064 μg/ℓ. Hence, 26% of the total Kepone is transported with sediment and 74% is in a dissolved form.

Similarly, the average annual net bed desposition rate for the 86-km tidal James River reach is estimated to be 0.7 mm/yr which agrees well with field data obtained during the last 70 years (Nichols, 1972). This also confirms the general validity of the present mathematical simulation.

Finally, it is estimated that 89.1 kg of Kepone per year are transported from the tidal James River towards Chesapeake Bay. Of that, 22.5 kg of Kepone are a particulate form associated with sediment, and 66.6 kg of Kepone are in a dissolved form. Since there are some possibilities that the contaminated sediment is deposited and/or dissolved Kepone is adsorbed by cleaner sediment between Burwell Bay and the James River mouth, 89.1 kg/yr is a conservative estimate. However, since 74% of the Kepone is in the dissolved form, it is judged that changes in the total Kepone concentration between Burwell Bay and the river mouth are not very significant.

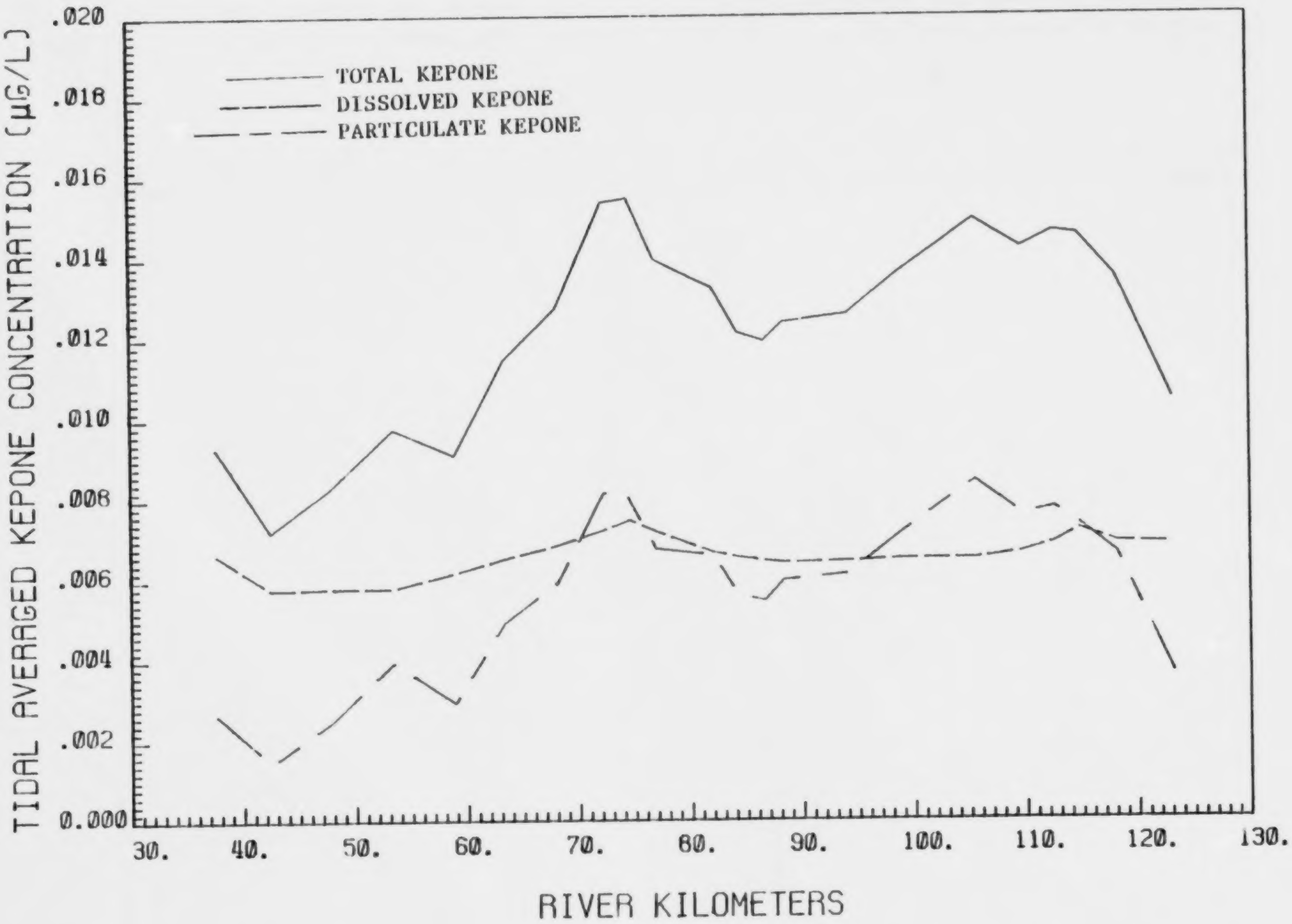


FIGURE VII.50. Longitudinal Distributions of Tidal Averaged Total, Dissolved and Particulate Kepone Concentrations for the Fresh-water Discharge of 681 m^3/sec

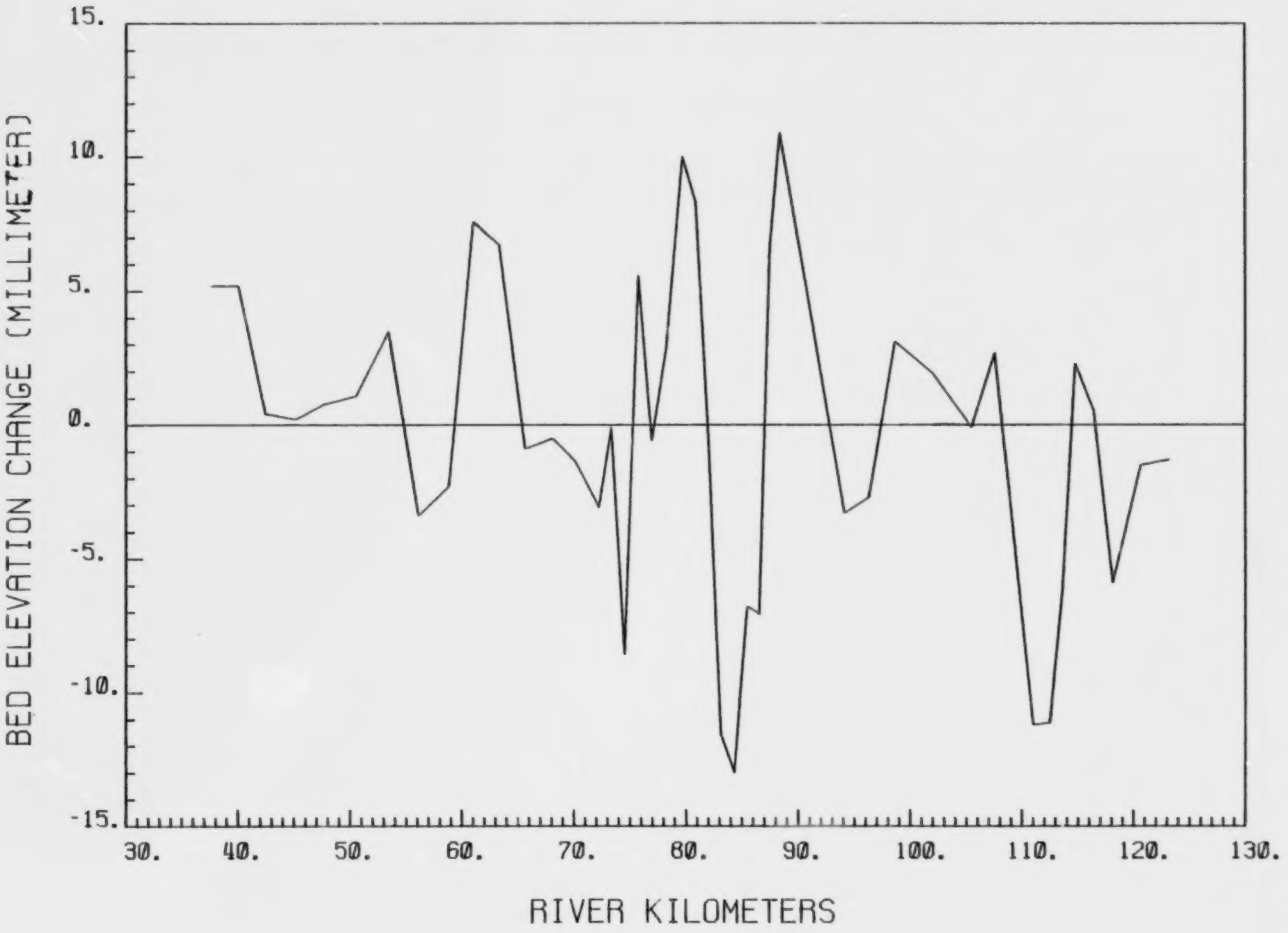


FIGURE VII.51. Variation of River Bed Elevation Changes Due to Sediment Deposition and/or Bed Scouring at Maximum Ebb Tide for the Fresh-water Discharge of 681 m^3/sec

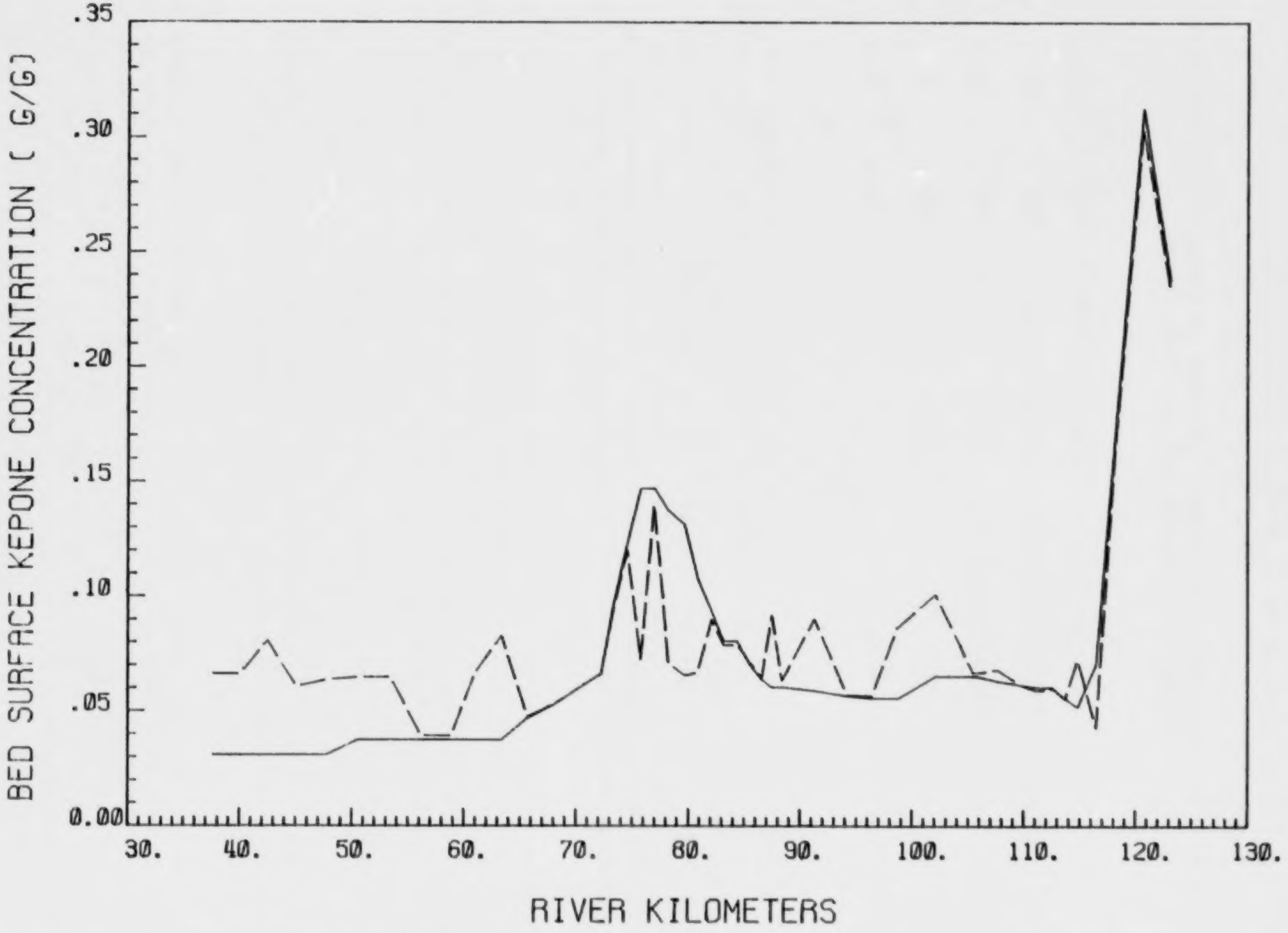


FIGURE VII.52. Change in Bed Surface Kepone Concentration Occurred During 1-Month Simulation for the Fresh-Water Discharge of 681 m^3/sec

The summary of the simulation results on Kepone migration from Burwell Bay seaward for all four cases is shown in Table VII.12.

TABLE VII.12. SUMMARY OF SIMULATION RESULTS ON KEPONE MIGRATION FROM BURWELL BAY SEAWARD FOR ALL FOUR CASES

	Case 1	Case 2	Case 3	Case 4
Fresh-water Input Discharge (m^3/sec)	58.3	247	681	321
Annual Total Kepone Discharge (kg/yr)	14.0	62.3	200	89.1
Dissolved Kepone Percentage (%)	84.3	80.0	72.0	74.7
Particulate Kepone Percentage (%)	15.7	20.0	28.0	25.3

Sensitivity Analysis--

In order to assess the response of the model, FETRA, a sensitivity analysis was conducted for some selected parameters and conditions. They included fresh-water discharge, sizes, fall velocity, and density of sediment, and three parameters affecting sediment erosion and deposition (critical shear stresses for erosion and deposition, erodibility constant shown in Equations 15 and 16 in Appendix M). Among these variables and parameters, the three sediment erosion and deposition parameters were found to have a strong influence on the sediment transport, as reported by Onishi (1977a,b).

Because of the strong interaction between Kepone and sediment, the distribution coefficient, K_{d_j}, describing the sorption-desorption equilibrium condition is one of the most important keys to accurate model prediction. To investigate this sensitivity as well as bed Kepone concentration a second series of simulations (Cases 5, 6, 7, and 8) was conducted employing a distribution coefficient of 2000 cm^3/g with river bed Kepone concentrations twice as much as those used in Cases 1 through 4. The distribution coefficient of 2000 cm^3/g is representative of those found in Bailey Bay and, as compared to 10,000 cm^3/g used for Cases 1 through 4, would reflect a high degree of Kepone availability for desorption from sediment to water as suggested by the laboratory studies conducted at the EPA Research Laboratory in Gulf Breeze (Garnas et al., 1977; U.S. EPA, 1978).

Test conditions for Cases 5 through 8 are the same as those of Cases 1 through 4 except the values of distribution coefficient and bed Kepone concentrations. Under these conditions, sediment transport is unaffected by a change in partitioning Kepone and therefore remains the same as previously reported. However, as expected, the dissolved Kepone levels for all these four cases become higher than those for Cases 1 through 4 and do not correspond as well with field data as the computer results of Cases 1 through 4.

Table VII.13 indicates the brief summary of results on Kepone migration from Burwell Bay toward Chesapeake Bay and Atlantic Ocean for this sensitivity case. As shown in Table VII.13, the amount of Kepone being transported from Burwell Bay toward Chesapeake Bay increases for these cases as compared to those of Cases 1 through 4; the results for the sensitivity analysis cases do not add significantly to the amount of Kepone transported past Burwell Bay each year. Hence, conclusions derived from computer results for Cases 1 through 4, will not change significantly with variation of the distribution coefficient and bed Kepone level tested in this study.

TABLE VII.13. SUMMARY OF SENSITIVITY ANALYSIS--KEPONE MIGRATION FROM BURWELL BAY SEAWARD

	Case 5	Case 6	Case 7	Case 8
Fresh-water Input Discharge (m^3/sec)	58.3	247	681	321
Annual Total Kepone Discharge (kg/yr)	35.8	135	350	170
Dissolved Kepone Percentage (%)	95	93	88	92
Particulate Kepone Percentage (%)	5	7	12	8

Kepone Cleanup Activities--

The model may also be used to answer questions about mitigation such as:

1. What will happen to the Kepone migration pattern and its concentration level if a part of the Kepone in the river bed is removed by physical, chemical or biological methods.
2. Where is the optimal location for Kepone removal to reduce the Kepone level in the River.

In order to answer these questions, further mathematical modeling was conducted for an additional 10 cases (Cases A through J) by assuming that for each case, Kepone in the bed at a certain part of the tidal James River was completely removed. This is accomplished by changing boundary conditions to assume no bed Kepone in the restored reach. For all cases, fresh-water input discharges were assumed to be 247 m^3/sec. Computer results during the maximum ebb tide after 1-month simulation for these cases were then compared with those of Case 2 (no cleanup activity was performed for Case 2) in order to assess the effectiveness of the Kepone cleanup activities.

Locations of Kepone cleanup activities are divided into four categories: (1) upper part of the River (Cases A, B, and C), (2) middle part of the River (Cases D through H), (3) lower part of the River (Case I), and (4) combination of (2) and (3) (Case J). Exact cleanup locations are shown in the lower parts of Figures VII.53 through VII.55, together with simulation results. Total, dissolved and particulate Kepone concentrations for Cases A through J and Case 2 are shown in Figures VII.53 through VII.55, respectively. In these figures, thick solid lines represent Case 2 (no cleanup activity).

In the cases of upper river cleanup activities (Cases A through C), Cases B (cleanup of Bailey Bay and upper half of Tar Bay) and C (Bailey and Tar Bay) indicate the improvement of river conditions for these cases by reducing concentrations of total, dissolved and particulate Kepone by up to approximately 15% within the vicinity of the cleanup locations. The cleanup activity conducted for Case A (cleanup of Bailey Bay) does not reduce the Kepone concentrations, as shown in these three figures.

In the case of middle river cleanup activities (Cases D through H), significant reduction of Kepone level (total, dissolved and particulate Kepone concentrations), up to 55 and 48%, was obtained for Cases D and E, respectively. The cleanup area of Case D is a 34.5-km reach between 50.5 and 85.0 River Kilometer, while a cleanup area for Case E is a 22-km reach between 56.0 and 78.0 River Kilometer. Cases G and H also demonstrate some reduction (up to approximately 13%); however, Case F does not show any improvement. For these five cases, there is not significant improvement near Burwell Bay, as shown in Figures VII.53 through VII.55.

For the case of cleanup activity in the lower river (Case I), there is no measurable reduction in the Kepone concentration. Consequently, the Case J (combination of Cases G and I) computer results are the same as those of Case G.

Among these 10 cases, Cases D and E reveal significant reduction of both dissolved and particulate Kepone concentrations. Although Case D (up to 55% reduction of Kepone concentration) is slightly better than Case E (up to 48% reduction), comparison of sizes of cleanup areas for these two cases (34.5 and 22.0 km reaches for Cases D and E, respectively) leads to the conclusion that Case E is more efficient to reduce the Kepone concentration in the River per unit area of cleanup activities.

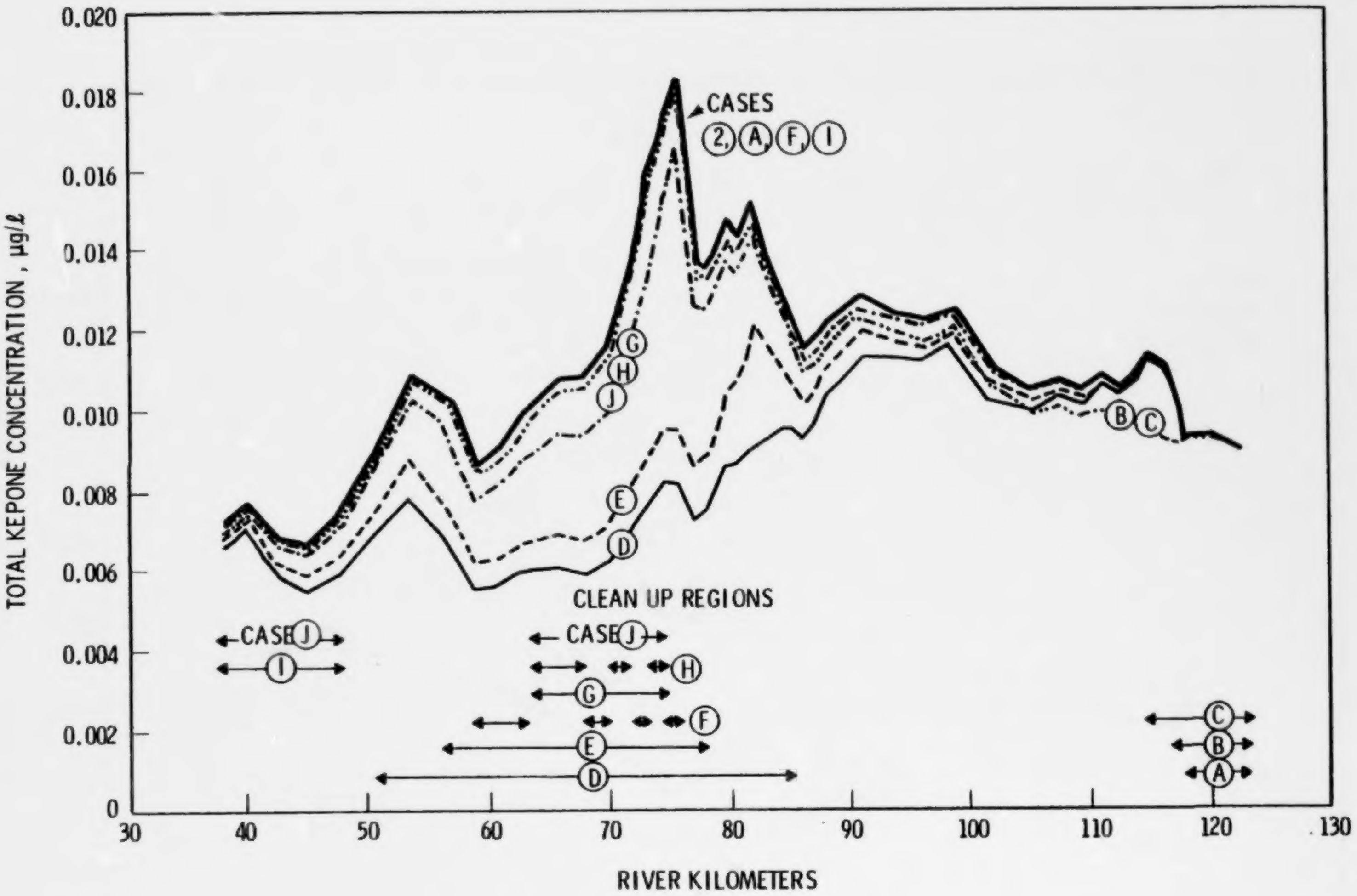


FIGURE VII.53. Changes in Total Kepone Concentrations Due to Partial Kepone Cleanup Activities

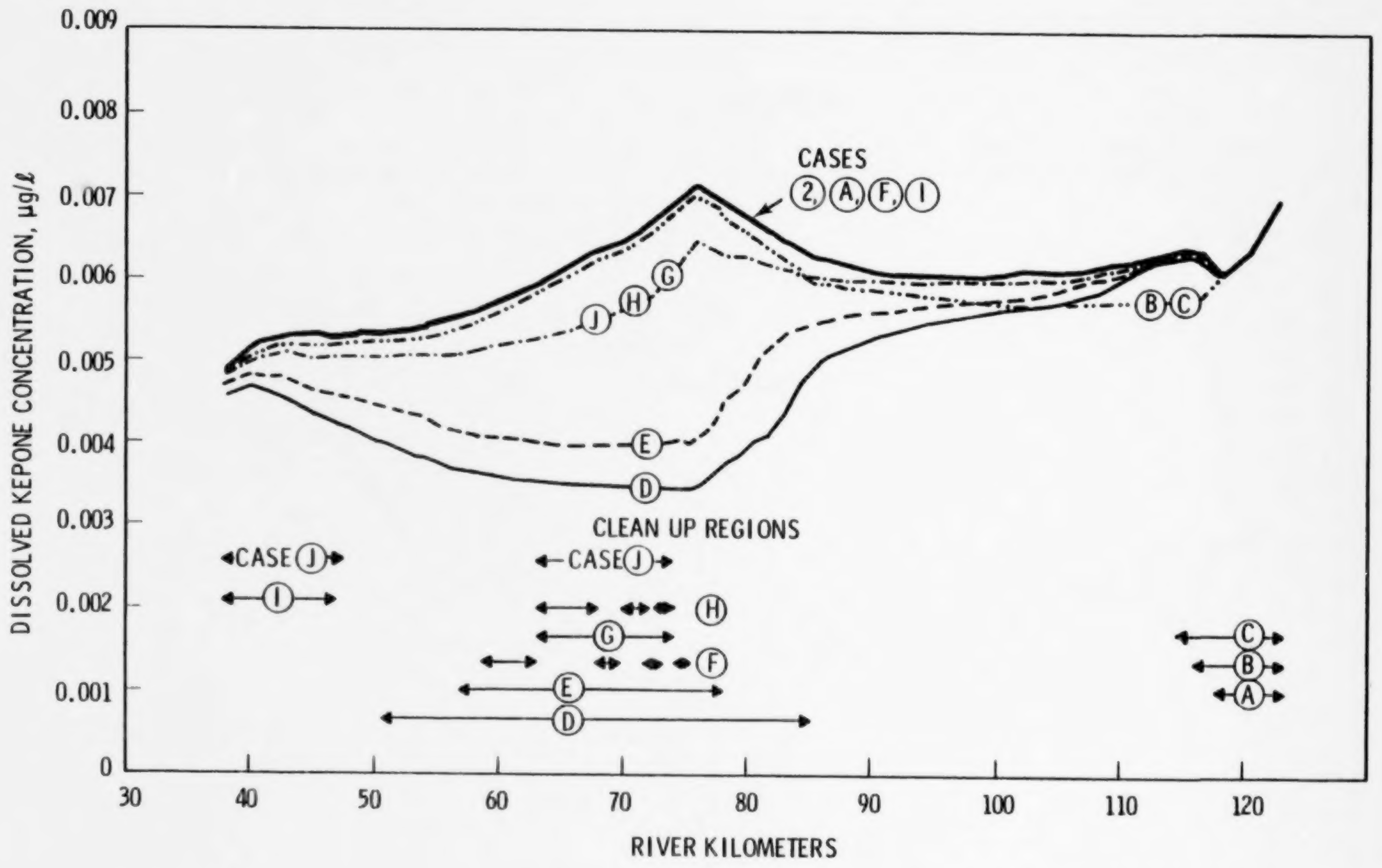


FIGURE VII.54. Changes in Dissolved Kepone Concentrations Due to Partial Kepone Cleanup Activities

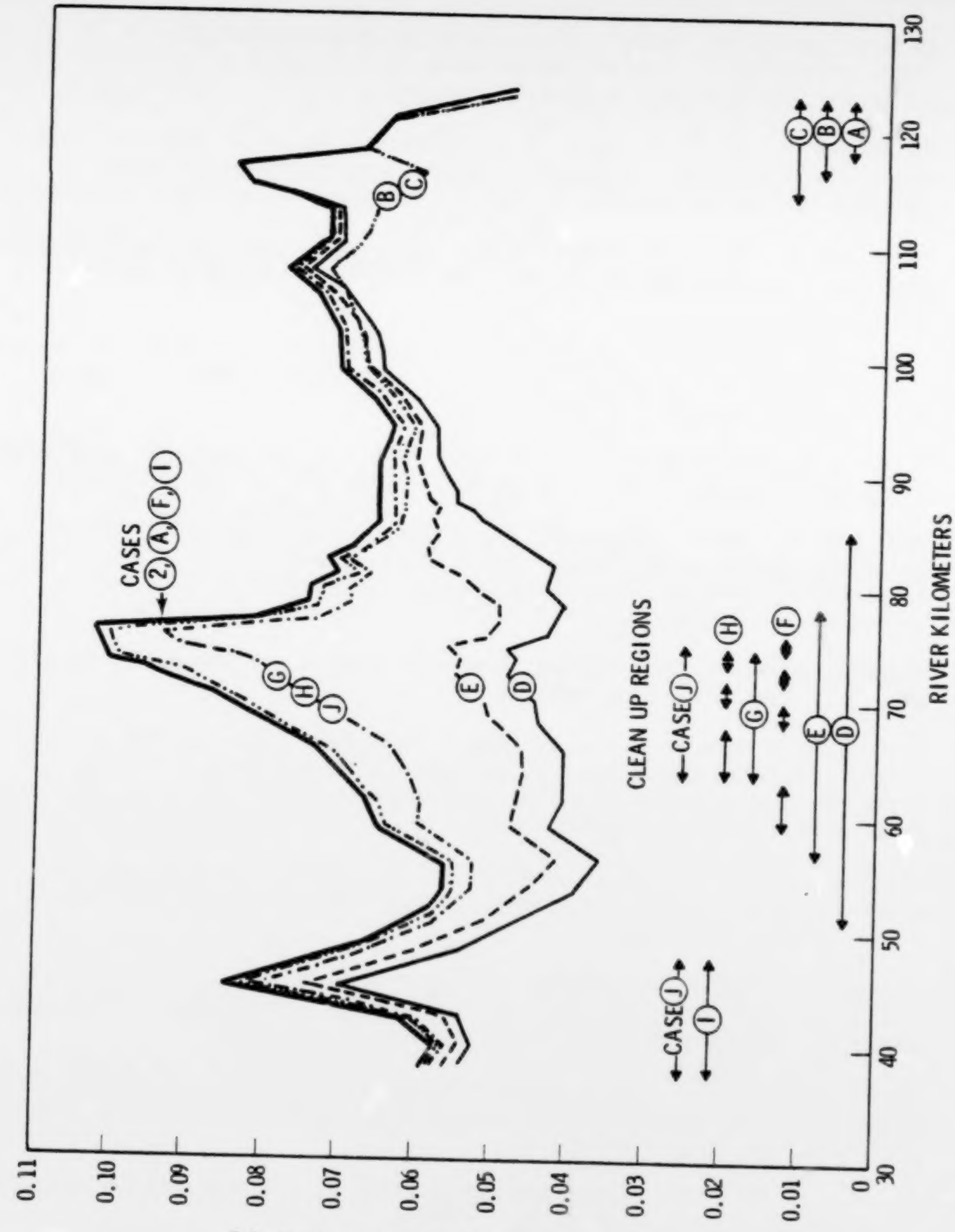


FIGURE VII.55. Changes in Particulate Kepone Concentrations Due to Partial Kepone Cleanup Activities

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CHAPTER VIII - ECOLOGICAL EFFECTS OF KEPONE

SUMMARY

Content

Chapter VIII is a compilation of information available on the impact of Kepone on aquatic species. A majority of the data presented resulted from research performed at the EPA's Environmental Research Laboratory at Gulf Breeze. Sections include discussions of acute toxicity, chronic toxicity, bioconcentration, bioaccumulation, and the implications of these processes to the James River ecosystem. Of particular interest is the relationship between Kepone levels in water and sediment to concentrations subsequently found in the aquatic species. This leads to discussions of alternative "no-effect" criteria and of the potential duration of environmental impact in the James River from persistent Kepone residuals.

Findings

- The fish species in the James River that is most sensitive to the acute toxic effects of Kepone is spot (*Leiostomus xanthurus*) with a 96-hr LC_{50} of 6.6 μg/ℓ (ppb).
- Sublethal effects with chronic exposure have been reported at Kepone concentrations in water as low as 0.05 μg/ℓ (ppb) (sheepshead minnows).
- Kepone bioconcentration factors calculated from laboratory studies range from 8.1 in blue crab to a high of 13,470 in mysid.
- The major route of Kepone uptake in fish is from Kepone dissolved or suspended in the water.
- Filter feeding shellfish take up Kepone from contaminated suspended solids.
- Bioaccumulation of Kepone from food and sediment is significant in blue crabs and polychaete worms.
- In laboratory studies, contaminated oysters depurated Kepone to non-detectable levels in 7 to 20 days.
- Fish species both bioconcentrate and depurate Kepone at slower rates than oysters.
- Analysis of field and laboratory data suggest that Kepone levels at or below 0.005 μg/ℓ (ppb) in water and 0.015 μg/ℓ (ppm) in bottom sediment would result in no adverse ecological impacts.
- The current FDA Action Limits are 0.3 μg/ℓ (ppm) Kepone in the edible meat of fish and shellfish, and 0.4 μg/ℓ (ppm) in blue crab.

INTRODUCTION

The importance of environmental levels and annual transport of Kepone in the James River is best determined in light of the ecological effects of Kepone. The U.S. Environmental Protection Agency's Environmental Research Laboratory at Gulf Breeze has determined these effects for many aquatic species as a part of the overall EPA Mitigation Feasibility Study. That work is reported in detail in a companion document "Kepone in the Marine Environment." A summary of pertinent data is presented here. Many of the referenced sources were authored by the Staff at Gulf Breeze and can be found in the above-mentioned compendium of publications and prepublications.

PHYSICAL-CHEMICAL CHARACTERISTICS OF KEPONE

Kepone is an extremely stable member of the cyclodiene insecticides. Perhaps the most important physical factor affecting its aquatic biological availability is its solubility in water. Within a pH range of 4 to 6 the solubility of Kepone ranges from 1.5 to 2.0 mg/ℓ (ppm). An increase of pH to 9 to 10 increases the solubility to 5 to 70 mg/ℓ (ppm). The second case is highly unlikely in a river system such as the James and therefore the first range can be taken as a working level for Kepone solubility. (High pH levels have been recorded in Bailey Creek, but not in the main channel of the River.)

Even with Kepone solubility ranging from 1.5 to 2.0 mg/ℓ (ppm) it is not likely that actual levels of Kepone in the James River water would be greater than 0.01 to 1.0 μg/ℓ (ppb). The reason for the difference is the high sediment load on the James River waters. Sediments, especially those of high organic content, have a very high affinity for Kepone. Thus, the amount of Kepone available to those organisms which could take it from the dissolved state is relatively small. On the other hand, those organisms such as oysters or other filter feeders which ingest water-borne sediments, will have more ready access to Kepone.

ACUTE TOXICITY

Only a limited number of species have been tested for acute sensitivity to Kepone (Table VIII.1). Of these only a few are residents of the James River. Toxicity data for species not found in the James River are of value, however, since extension of data on representative species is valid for many contaminants. While specific values cannot be obtained from such an extension, one can define a range of general toxicity.

The response of redear sunfish, Lepomis microlophus, to Kepone was investigated by Bridges (1962) who found that the 96-hr LC_{50} for Kepone varied with exposure temperature. At a water temperature of 45°F the LC_{50} was 140 μg/ℓ (ppb), while at a higher temperature of 85°F the lethal level was reduced to 29 ppb. Therefore, the toxicity of Kepone to the redear sunfish is 7.1 times greater at 85°F than at 45°F. In studies conducted by Bentley (1975) both bluegill sunfish and rainbow trout were tested.

TABLE VIII.1. ACUTE TOXICITY VALUES OF KEPONE TO SELECTED SPECIES

Species	96 hr LC_{50}, µg/ℓ-(ppb)	Reference
Redear Sunfish *Lepomis microlophus*	140.0 at 45°F 29.0 at 85°F	Bridges, 1962
Bluegill *Lepomis macrochirus*	51.0	Bentley, 1975
Rainbow Trout *Salmo gairdneri*	36.0	Bentley, 1975
Fiddler Crab *Uca pugilator*	1470.0	Heitmuller, 1975
Mysid *Mysidopsis bahia*	10.1	Nimmo et al., 1977
Brown Shrimp *Panaeus aztecus*	85.0 LE EC_{50}, 24 hr	Butler, 1963
Oyster *Crassostrea virginica*	15 - 57.0 shell growth EC_{50} 48 hr	Butler, 1963
Grass Shrimp *Palaemonetes pugio*	121.0	Shimmel and Wilson, 1977
Blue Crab *Callinectes sapidus*	210.0 (no mortality)	
Sheepshead Minnow *Cyprinodon variegatus*	69.5	Shimmel and Wilson, 1977
Spot *Leiostomus xanthurus*	6.6	Shimmel and Wilson, 1977

The bluegill sunfish species is found in limited numbers in the fresh-water portion of the James River, while the rainbow trout species is not found in the tidally influenced waters of the James (Chapter VI). The 96-hr LC_{50} for the bluegill was determined to be 51 µg/ℓ (ppb); for the trout it was slightly lower at 36 µg/ℓ (ppb). In this static bioassay the fish generally demonstrated lethargy, discoloration, loss of equilibrium and death. For the fiddler crab, *Uca pugilator*, sensitivity was investigated by Heitmuller (1975). The 96-hr LC_{50} was found to be 1470 µg/ℓ (ppb). This species of crab is not found in the James estuary.

Although not found in the James River, the brown shrimp *Panaeus aztecus* is closely related to two other panaeid shrimps which are. Studies have indicated the effective concentration for 50% loss of equilibrium or death was 85 µg/ℓ (ppb) (Butler, 1963). Another study indicated that for an important James River species, the eastern oyster, *Crassostrea virginica*, the growth rate of the shell was reduced in 50% of the exposed organisms in the range of 15 to 57 µg/ℓ (ppb) depending upon the salinity (Butler, 1963).

One of the most important organisms in the food chain of the Chesapeake Bay tributaries is the opposum shrimp, a mysid. These organisms represent an important component of the food for such fish species as weakfish, *Cynoscion regalis*; shad, *Alosa sapidissima*; blueback herring, *Alosa aestivalis*; alewife, *Alosa pseudoharengus*; bay anchovy, *Anchoa mitchilli*; striped bass, *Morone saxatilis*; and white perch, *Morone americana* (Hildebrand and Schroeder, 1972). Most of the species listed use mysids as a food during the juvenile stages; however, some feed on mysids throughout their life cycle, e.g., white perch and bay anchovy. The only mysid listed in the most recent species check list for the James River is *Neomysis americana* and from the list of fishes above it should be an important member of the food chain. However, gut analysis of striped bass from the James revealed no mysids. This was in direct contrast to mysid levels of 14% found in striped bass from the York and Rappahannock Rivers. Toxicity data for Kepone effects on mysids are available for *Mysidopsis bahia* (Nimmo et al., 1976). Although the quantitative toxicity data for *M. bahia* cannot completely substitute for missing data on *N. americana* it should be noted that in recent EPA studies *M. bahia* was one of the most sensitive species to Kepone that has been examined (Hansen et al., 1976). Therefore, the information available on *M. bahia* may well identify the lower limits of toxicity and Kepone interference with the normal growth and production of *N. americana*. The EPA studies with *Mysidopsis* bahia determined a 96-hr LC_{50} for Kepone of 10.1 µg/ℓ (ppb) at 25 to 28°C and 10 to 16 ppth salinity. In a life cycle study it was determined that the opposum shrimp were stunted and that the average number of young produced by females previously exposed to Kepone was halved by exposure to 0.39 µg/ℓ (ppb) Kepone throughout the 19-day study (Nimmo et al., 1976).

The most pertinent studies thus far have been conducted by the EPA laboratory at Gulf Breeze, Florida (Schimmel and Wilson, 1977). Four species of estuarine organisms known to occur in the James River waters were investigated for acute toxicity and bioconcentration. The organisms were grass shrimp, *Palaemonetes pugio*; blue crab, *Callinectes sapidus*; sheepshead minnow, Cyprinodon variegatus; and spot, Leiostomus xanthurus. Dissolved Kepone was found to be acutely toxic to the fish species and to the shrimp but not to the blue crab. The maximum concentration tested was 210 μg/ℓ (ppb) but the maximum mortality of blue crabs was only 10%. The 96-hr LC_{50} varied widely for the remaining species. The most sensitive species tested was spot which had an LC_{50} of 6.6 μg/ℓ (ppb). The sheepshead minnow was 10 times higher at 69.5 μg/ℓ (ppb). The grass shrimp was even more tolerant with a LC_{50} of 120.9 μg/ℓ (ppb) and, as was stated above, no acute toxicity was demonstrated for the blue crab at the concentrations tested. The signs of toxicity in the fish were similar regardless of the species and are similar to those reported by Bentley (1975) for blue gills and rainbow trout. Generally the fish became lethargic and lost equilibrium before death. The advanced stage of toxicity was usually noted by discolorations in various areas of the body. This similarity may be indicative of the mechanism of lethality.

CHRONIC TOXICITY, BIOCONCENTRATION, AND BIOACCUMULATION

Knowledge of the toxicant concentration which will kill an organism in a standard length of time, usually 96 hr, is valuable information for comparing the relative toxicity of different toxicants. In addition, this information will allow the prediction of field mortality in an acute exposure situation. In most cases of contamination of a natural water system, toxicant concentrations are below the laboratory determined acute LC_{50} value as a result of solubility, dilution, etc. When this occurs, the information required for impact analysis is the effect of chronic exposure, e.g., the effective concentration, usually stated as an EC_{50}, which will elicit some sublethal response. The response can be a number of different indicators, such as growth, reproduction, and behavioral changes. All of these items can be just as important to the survival and well being of a species as a mortality due to a massive dose.

When considering a persistent organochlorine compound like Kepone the other factor which must be considered is the ability of the organisms to bioconcentrate the material directly from the dissolved state in the water column and to pass it on to the higher trophic levels. The latter situation occurs through a food chain where a prey organism carrying a body burden of Kepone is consumed by a predator which then accumulates some or all of the Kepone in its prey. It is through this mechanism that persistent compounds have been shown to accumulate and can become a threat to the health of both the upper levels of the aquatic ecosystem and to man as a consumer of aquatic species.

Questions of chronic toxicity, sublethal response, bioconcentration, and bioaccumulation have been addressed in a number of Kepone studies. The most pertinent Kepone investigations have been summarized in Table VIII.2 and are discussed below.

TABLE VIII.2. CHRONIC EFFECTS, BIOCONCENTRATION AND BIOACCUMULATION OF KEPONE

Species	Exposure (ppb)	Result	Tissue Concentration (ppm)	Bioconcentration Factor	Bioaccumulation Factor	Reference
Chlorococcum sp.	100 ppb, 24 hr	EC_{50}(growth) = 0.35 ppm	80.0 ppm	800		Walsh et al., 1977
Dunaliella tertiolecta	3 times in 7 day	= 0.58 ppm	23.0 ppm	230		
Nitzshia sp.		= 0.60 ppm	41.0 ppm	410		
Thalossiosira psuedonana		= 0.60 ppm	52.0 ppm	520		
Grass shrimp	12-121 ppb		5.1-94.0 ppm	698		Schimmel and Wilson, 1977
Paleomonetes pugio	96 hr					
Blue Crab	110-210 ppb		0.85-1.3 ppm	8.1		
Callinectes sapides						
Sheepshead minnow	7.1-78.5 ppb		11.2-118.4 ppm	1,548		
Cyprinodon variegatus						
Spot	1.5-15.9 ppb		1.7-16.8 ppm	1,221		
Leiostomus xanthurus						
Oyster	0.03-0.39 ppb		0.29-3.6 ppm	9,354-9,278	Algae → Oyster = 2.1	Bahner et al., 1977
Crassostrea virginica	28 day				Water → Algae → Oyster = 0.007	
Mysid	0.026-0.41 ppb		0.19-6.3 ppm	5,962-13,473	Brine shrimp → mysids = 0.53	
Mysidopsis bahia	21 day					
Grass shrimp	0.023-0.40 ppb		0.09-4.57 ppm	5,127-11,425		
Paleomonetes pugio	28 day					
Sheepshead minnow	0.05 ppb		0.37 ppm	7,115		
Cyprinodon variegatus	28 day					
Spot	0.029-0.40 ppb		0.06-0.99 ppm	3,217-2,340	Mysid → Spot = 0.85	
Leiostomus xanthurus	30 day				Brine shrimp → mysid → Spot = 10.5	
Sheepshead minnow						
Cyprinodon variegatus						
Adults	0.05-24.0 ppb 28 day	LC_{50} = 1.3 ppb	0.25-12 ppm	5,200		Hansen et al., 1977a
Juveniles	0.08-33 ppb 36 day	LC_{50} = 6.7 ppb	0.13-22 ppm	7,200		

The lowest level in the food web of an aquatic system contains the primary producing organisms, the algae. Walsh et al. (1977) determined the effective concentrations of Kepone which will diminish the growth of four algal species. Two of the species studied were green algae, Chlorococcum sp. and Dunaliella tertiolecta, while the other two were diatoms, Nitzschia sp. and Thalassiosira pseudonana. Walsh conducted 7-day tests of the effect of Kepone on the growth of these species of algae. Cultures were exposed to 100 μg/ℓ (ppb) at three times during the 7-day tests. The results in terms of EC_{50} for growth shows that Chloroccoccum sp. is the most sensitive at 0.35 μg/g (ppm). The other three species were very similar in response with EC_{50} values of 0.58 μg/g (ppm) for Dunaliella tertiolecta; 0.60 μg/g (ppm) for Nitzschia sp. and Thalassiosira psuedonana. The exposure concentrations in this laboratory study were considerably higher than those which might be expected in the James River and therefore it is doubtful that Kepone would be a factor in reducing the productivity of phytoplankton. In companion studies Walsh determined the bioconcentration factors for the same four species of algae. The results were Chlorococcum sp., 800; Dunaliella tertiolecta, 230; Nitzschia sp., 410; and Thalassiosira psuedonana, 520. While the algal productivity may not be affected at field concentrations, it is apparent that the algae may be expected to bioconcentrate Kepone and thus serve as a source of Kepone at the base of the food web.

The possibility of bioconcentration by higher trophic levels was investigated by Schimmel and Wilson (1977). The primary objective of this study was to determine the acute toxicity of Kepone to grass shrimp, Palaemonetes pugio; blue crab, Callinectes sapidus; sheepshead minnow, Cyprinodon variegatus; and spot, Leiostomus xanthurus, which was discussed above. The survivors of this study were pooled for tissue analysis with the following bioconcentration factors resulting: blue crab, 8.1; shrimp, 696; spot, 1221; and sheepshead minnow, 1548. These results are similar to bioconcentration factors found with other organochlorine toxicants. No explanation was offered for the relatively low bioconcentration factor for the blue crab. The measured tissue level ranged from 0.85 to 1.2 μg/g (ppm) which is comparable to the tissue levels that have been measured in blue crabs taken from the field. Bender et al. (1977) reported at the Kepone Seminar II on September 20-21, 1977 that the average tissue concentration for female blue crabs was 0.19 and males averaged 0.81 μg/g (ppm).

One of the most significant studies of Kepone to date was conducted by Bahner et al. (1977) of the EPA Gulf Breeze Laboratory. The objectives of the program were to determine: (1) the rate and magnitude of Kepone bioconcentration from water; (2) rates of Kepone depuration; and (3) the rate of Kepone bioaccumulation through a laboratory food chain. The organisms used in this study were eastern oysters, Crassostrea virginica; mysids, Mysidopsis bahia; grass shrimp, Palaeomonetes pugio; sheepshead minnow, Cyprinodon variegatus; and spot, Leiostomus xanthurus. The organisms in the study were collected from the field, acclimated in the laboratory and then exposed to two concentrations of Kepone in aquaria. All species were held for periods up to 30 days in Kepone treated water and then held for a similar period in Kepone-free water (except for the mysids) to investigate the capacity for depuration.

Kepone was bioconcentrated by all species with equilibrium levels being attained within 8 to 17 days of exposure. Approximate bioconcentration factors for each species were: spot, 3,000; grass shrimp, sheepshead minnow, 7,000; oysters, 13,000; and mysids, 10,000. Kepone was bioconcentrated more efficiently by the crustaceans with increasing concentrations in the water. The fish with uptake rates slower than the oysters reached equilibrium levels in 10 to 20 days. The edible fillets of the spot contained approximately the same concentration as the whole fish; thus the edible portion represents one of the largest reserves of Kepone. As with bioconcentration, Kepone depuration was most rapid in the oysters, with Kepone reaching nondetectable levels within 7 to 20 days. Other organisms were much slower, particularly grass shrimp and fish. Kepone concentrations in these latter organisms remained 50 to 70% of peak value as much as 24 to 28 days after initiation of depuration.

In companion studies, Bahner et al. (1977) investigated the bioaccumulation of Kepone via laboratory food chains. Kepone-contaminated algae, Chlorococcum sp. was fed to oysters. The oyster tissue reached equilibrium within 14 days but the quantity of Kepone transferred was small. The measured Kepone concentration in the algae was 34 μg/g (ppm). After 14 days of feeding oyster tissue concentration reached 0.21 μg/g (ppm). When the feeding was terminated most of the Kepone was depurated within 96 hr. Thus the rate of depuration is rapid and oysters taken from the field with tissue levels that are detectable must come from areas where the water and/or the food contain a continuous source of Kepone. The bioaccumulation factor for oysters fed contaminated food was 0.007. The food chain bioaccumulation factor, i.e., water-algae-oyster, was 2.1, however (concentration in oysters to that in water originally).

In a plankton-mysid-fish food chain, spot accumulated Kepone after eating mysids which had accumulated Kepone from Kepone-contaminated brine shrimp which they had eaten. The brine shrimp had concentrated Kepone from the water to which they were exposed for 48 hr. The brine shrimp were exposed to two levels of Kepone and thus there were two study chains, low and high exposure. The bioconcentration of Kepone by brine shrimp was a factor of 10 for the low exposure and 23.3 for the high exposure. The bioaccumulation factor from brine shrimp to mysids was 0.5 in both cases and from mysids to spot it was 0.85. Spot were fed Kepone-contaminated mysids for 30 days but the tissue concentration in spot never reached an equilibrium point (stable ceiling value) indicating that uptake of Kepone exceeded depuration and hence net uptake continued. The bioaccumulation factors at the links in this simple food chain suggest that bioaccumulation of Kepone is a relatively inefficient mechanism, the overall accumulation factor for the chain was only 10.5. Approximately 3,000 times as much Kepone in the food chain was required to produce the same tissue levels as that which would be bioconcentrated by the top organism, spot. However, there was a measurable amount of bioaccumulation and it does represent a means of Kepone transport through a food chain.

The chronic effect of Kepone on sheepshead minnow growth and survival of embryo, fry and juveniles was investigated by Hansen et al. (1977a). Adult sheepshead were held in Kepone concentrations ranging from 0.05 to 24.0 μg/ℓ (ppb) for 28 days. All the fish in the highest two concentrations [7.8 and 24 μg/ℓ (ppb)] died. Symptoms of poisoning during the exposure were darkening of the posterior of the body, hemorrhaging near the brain, fin rot, loss of swimming coordination, cessation of feeding, and scoliosis. Scoliosis was also reported by Couch et al. (1977). Survivors of the 28-day bioassay were spawned and the progeny observed for survival, growth, hatching, and development in a 36-day exposure to six concentrations ranging from 0.08 to 33.0 μg/ℓ (ppb) Kepone. A significant portion of the embryos from adults exposed to 1.9 μg/ℓ (ppb) died during embryogenesis even when held in Kepone-free water. Also, the Kepone bioconcentrated by the adults (factor = 5200) and passed to the embryos was very slow to depurate. Forty-six percent of the Kepone in the egg was still found in the fry 36 days after hatching. The fry exposed to 0.08 μg/ℓ (ppb) were stunted. The conclusion reached by Couch et al. was that the acute toxicity results available for Kepone greatly underestimate the true hazard of the chemical to fish. Where the 96-hr LC_{50} for Kepone was found to be 6.96 μg/ℓ (ppb) for adult fish, the 28-day LC_{50} was 0.8 μg/ℓ (ppb) for adult fish and the 28-day EC_{50} was 0.8 μg/ℓ (ppb) for fry. Growth, reproduction and survival was affected by all concentrations studied. While it is generally accepted that one-hundredth (0.01) of the 96-hr LC_{50} for persistent organism chemical should protect species (NAS-NAE, 1973), the data developed in this study indicate that a concentration one thousandth (0.001) of the 96-hr LC_{50} was detrimental to the sheepshead minnow.

IMPLICATIONS OF KEPONE EFFECT STUDIES

The environmental impact assessment process for a persistent toxic material such as Kepone requires certain information. The acute and chronic toxicity to species in the water system in question is necessary. This information serves as the base for prediction of damage at the organism level in terms of direct lethality or sublethal effects such as inhibition of growth, behavioral alterations, and interference with reproduction. Bioconcentration and bioaccumulation factors must also be addressed in dealing with persistent compound classes which may have demonstrated a propensity for this activity. The details of information on these topics have been discussed above, and a general overview of this information is seen in Table VIII.3. Inspection of this table will reveal the major shortcoming of the toxicological data that are available for the compound Kepone. At the top of the table is listed the species for which data exist on the topics of toxicity, bioconcentration and bioaccumulation. Each of the species listed in the table has been rated as to its presence or absence in the James River ecosystems. If the species is found in the waters of the James River it is rated as to its importance based on abundance. Of the 13 species for which data exist only six are found in the river. Only three of these six, blue crab, oyster, and spot, are of economic significance. This is in direct contrast to a list of 21 additional species which are of importance to the river ecology for which no data are available.

TABLE VIII.3. COMPARISON OF SPECIES BASED ON LABORATORY DATA AVAILABLE AND IMPORTANCE TO THE JAMES RIVER

	James River		James River Importance	Acute Toxicity	Chronic Toxicity	Bioconcentration	Bioaccumulation
	Absent	Present					
Green Algae							
Chlorococcum sp.	A				X	X	
Dunaliella tertiolecta	A				X	X	
Diatoms							
Nitzschia sp.		P	Ab		X	X	
Thalassiosira pseudonana		G			X	X	
Mysids							
Mysidopsis bahia	A			X		X	X
Brine Shrimp							
Artemia salina	A					X	
Grass Shrimp							
Palaemonetes pugio		P		X		X	
Brown Shrimp							
Panaeus aztecus		G		X			
Fiddler Crab							
Uca pugillator	A			X			
Blue Crab							
Callinectes sapidus		P	Ab	T		X	
Oyster							
Crassostrea virginica		P	Ab	NA	X	X	X

A = Absent NA = Not applicable D = Dominant in some salinity zones P = Present C = Common
G = Genus present, other species Ab = Abundant in some salinity zones and seasons T = Tested, none determined

TABLE VIII.3. (contd)

	James River Absent	James River Present	James River Importance	Acute Toxicity	Chronic Toxicity	Bioconcentration	Bioaccumulation
Redear Sunfish							
Lepomis microlophus	A			X			
Bluegill Sunfish							
Lepomis macrochirus		P	C	X			
Sheepshead Minnow							
Cyprinodon variegatus		P	C	X	X	X	
Spot							
Leiostomus xanthurus		P	D	X	X	X	X
Asiatic Clam							
Corbicula manilensis		P	D				
Wedge Clam							
Rangia cuneata		P	Ab				
Amphipod							
Gammarus daiberi		P	Ab				
Polycheate							
Scolecolepides viridis		P	Ab				
Soft Clam							
Mya arenaria		P	Ab				
Hard Clam							
Mercenaria mercenaria		P	Ab				
Channel Catfish							
Ictalurus punctatus		P	D				
Brown Bullhead							
Ictalurus nebulosus		P	D				
White Catfish							
Ictalurus catus		P	D				

TABLE VIII.3. (contd)

	James River		James River	Acute	Chronic		
	Absent	Present	Importance	Toxicity	Toxicity	Bioconcentration	Bioaccumulation
Hogchoker							
Trinectes maculatus		P	D				
White Perch							
Morone americana		P	D				
Bay Anchovy							
Anchoa mitchilli		P	D				
Striped Bass							
Morone saxatilis		P	C				
Silver Perch							
Bairdella chrysura		P	C				
Weakfish							
Cynoscion regalis		P	C				
Summer Flounder							
Paralicthys dentatus		P	C				
Blueback Herring							
Alosa aestivalis		P	C				
Alewife							
Alosa psuedoharengas		P	C				
Spottail Shiner							
Notropis hudsonius		P	C				
Atlantic Croaker							
Micropogon undulatus		P	C				
Spotted Hake							
Urophycis regius		P	C				

The latter part of the species list is by no means inclusive of all James River species but only lists those indicated as abundant or dominant in the benthic or pelagic communities (See Chapter VI). The use of representative species in toxicological studies is not unprecedented. Economics and resource limitations mediate against evaluation of all pertinent species for a particular water body. Historically, data on related species have been of value in assessing relative effects and determining likely impacts.

The acute toxicity data for all species indicate that the lethal concentrations, i.e., the 96-hr LC_{50} are all higher than the levels found dissolved in the water of the James. In part this is due to the low solubility of Kepone but it is especially the result of the high Kepone affinity of the sediments. The conclusion is that organisms which would be exposed to dissolved Kepone, mainly finfish, are not likely to experience acute toxicity. The concentrations of Kepone in the water column are much lower than the typical lethal levels as generated in the laboratory. For economically important organisms which are in contact with the sediment, i.e., blue crabs and oysters, no acute toxicity is demonstratable from the available data. Blue crabs were relatively unaffected by levels as high as 210 ppb and oysters typically cease siphoning in the presence of noxious materials or in the case of Kepone are quick to depurate.

The primary productivity of the James River is not likely to be affected by Kepone because of its low availability to the algae. The levels required to reduce the productivity of the algae species studied was approximately 100 times higher than the level typically found in the water column. It has been suggested that, while the primary productivity may not be affected, the bioconcentration performed by the algae may serve as a source for bioaccumulation at the higher trophic levels. Factors pertinent to this consideration are discussed below.

A review of the summarized acute toxicity data in Table VIII.1 provides an indication of the more sensitive organisms. Compared to the algae, benthos, and most finfishes listed in Table VIII.3, the mysids are probably the most vulnerable. As previously noted, mysids were conspicuously absent from the gut of James River striped bass. This may indicate direct effects of Kepone contamination which have caused a change in food sources for predators.

It has been stated above that the concentrations of Kepone used in the toxicity studies discussed were higher than those expected in the James River waters. From this data it might be concluded that the fish populations are relatively safe from acute effect. The chronic toxicity studies are another matter. Several studies of chronic effects indicate that Kepone is toxic to the species studied at very low concentrations. Rapid uptake has been demonstrated for migratory species as well as long-term residents.

Persistent organics such as DDT, lindane, toxaphene, and dieldrin are known to bioconcentrate and the mechanism is thought to be the relatively high solubility of the compounds in the fatty tissues of the organisms affected. Bioconcentration represents a mechanism for transfer of toxicants in organisms which then act as a source of the toxicant for the organisms at higher trophic levels. Table VIII.4 presents a summary of data on tissue concentrations of Kepone in various species. The data were derived from two sources, laboratory studies in which selected organisms were exposed to concentrations of Kepone and animals collected from the James River. The data in the upper portion of the table were selected from the literature on the basis of exposure levels which were most representative of what can be assumed to be the case in the environment, i.e., a long-term, low-level exposure. The field data were taken from Bender et al. (1977). Unfortunately, it is impossible to know the exact exposure concentration of the field biota but in this discussion a nominal concentration in the James River of 0.01 to 0.1 μg/ℓ (ppb) has been assumed. Thus, the exposure levels in the laboratory studies cited are in the same range and the tissue levels are similar. Inspection of the data by Bender revealed some interesting trends concerning what can be expected in James River biota. The fresh-water fish revealed the greatest variation in tissue levels of Kepone, ranging from 0.004 to 2.4 μg/g (ppm). The long-term estuarine residents were much less variable but showed the same upper limit. Values for these species range from 0.6 to 2.7 μg/g (ppm). The short-term marine species had the lowest tissue level of 0.1 μg/g (ppm) while the long-term marine finfish ranged from 0.75 to 0.81 μg/g (ppm). This comparison of data derived from the laboratory and field indicates that the information from the laboratory concerning rates, mechanisms, and depuration is applicable since similar exposures in laboratory and field result in similar tissue concentrations.

Bioconcentration is a dynamic process which means that tissue concentration of a chemical is time dependent and further that removal of the organism from the source of the dissolved chemical usually results in depuration. Since most of the James River fisheries have been closed due to the excessive tissue levels of Kepone, the rates and mechanisms of bioconcentration and depuration are critical items of information. The data of Bahner et al. (1977) and others indicate that the fish bioconcentrate Kepone to an equilibrium level in 8 to 17 days; oysters are much faster. Depuration displays a similar pattern, i.e., oysters depurated Kepone to nondetectable levels in 7 to 20 days in the laboratory, while bluefish have been noted to require more than 90 days to depurate. The field program of the Virginia Institute of Marine Science (Bender et al., 1977) included the sampling of Kepone-laden oysters from the James River and moving them to uncontaminated areas. These transplanted oysters were then sampled over time to determine the effect of season on the depuration rate. As might be expected the oysters depurate more slowly in the winter when activity levels are depressed. The biological half-life of Kepone in oysters in the summer is about 1 week while in the winter 40 days are required before there is a measurable decline in the residue levels. Measured tissue concentrations in light of the rapid depuration rate of oysters in the summer indicate that they must be in continuous contact with water carrying Kepone or have access to Kepone-laden food and sediments.

TABLE VIII.4. COMPARISON OF TISSUE CONCENTRATIONS OF KEPONE RESULTING FROM CHRONIC LABORATORY EXPOSURE WITH TISSUE CONCENTRATION MEASURED IN FIELD SAMPLED ORGANISMS

Organisms	Laboratory Exposure, ppb		Field Tissue, ppm
Laboratory Studies			
Algae			
Chlorococcum sp.	100, 3 times over 7 day		80.00
Dunaliella tertiolecta			23.00
Nitzschia, sp.			41.00
Thalassiosira psuedonana			52.00
Mysids			
Mysidopsis bahia	0.026	21 day	0.19
	0.41	21 day	6.30
Oyster			
Crassostrea virginica	0.03	28 day	0.29
	0.39	28 day	3.60
Grass Shrimp			
Palaemonetes pugio	0.023	28 day	0.09
	0.40	28 day	4.57
Sheepshead Minnow			
Cyprinodon variegatus	0.05	28 day	0.37
Spot			
Leiostomus xanthurus	0.029	30 day	0.06
Field Studies			
Spottail Shiner (Notropis hudsonius)	Unknown		0.08
Channel Catfish (Ictalurus punctatus)	"		0.04
White Catfish (Ictalurus catus)	"		0.25
American Eel (Anguilla rostrata)	"		0.64
Black Crappie (Promoxis nigromaculatus)	"		1.0
Largemouth Bass (Micropterus salmoides)	"		2.4
White Perch (Roccus americanus)	"		2.7
Bay Anchovy (Anchoa mitchilli)	"		0.65
Atlantic Silverside (Menidia menidia)	"		1.6
Hogchoker (Trinectes maculatus)	"		0.94
Grass Shrimp (Palaemonetes pugio)	"		0.60

TABLE VIII.4. (Contd)

Organisms	Laboratory Exposure, ppb	Field Tissue, ppm
Sand Shrimp (Crangon septemspinosa)	Unknown	2.0
Xanthid Crabs	"	0.27
Blue Crab (Callinectes sapidus) Female	"	0.19
Blue Crab (Callinectes sapidus) Male	"	0.81
Oyster (Crassostrea virginica)	"	0.16
Hard Clam (Mercenaria mercenaria)	"	0.09
American Shad (Alosa sapidissima)	"	0.03
Atlantic Menhaden (Brevoortia tyrannus)	"	0.05
Spot (Leiostomus xanthurus)	"	0.81
Croaker (Micropogon undulatus)	"	0.75
Bluefish (Pomatomus saltatrix)	"	0.29

The relatively slower rate of the fish to concentrate and depurate Kepone is important. In terms of the migratory fishes that use the James River for spawning grounds, it means that those fishes spending more than a month in the waters of the James River probably will reach equilibrium. However, it is likely that the rate of Kepone uptake for fish is depressed in the winter when water temperatures are lower. No data have been found, however, to support this.

There does not appear to be grounds for describing Kepone concentration by the same mechanism as many of the organochlorine compounds which seem to be lipophilic (Bender et al., 1977). The tissue level of Kepone found in the white catfish and the channel catfish differ considerably. White catfish have a measured mean concentration of 0.25 μg/g (ppm) from field samples and channel catfish have a mean concentration of only 0.04 μg/g (ppm). Both fish species occupy the same area of the James River and eat the same food. An explanation for the difference in Kepone levels is not found in the relative body fat content. The white catfish average lipid content is 9.6 mg/g (ppth) while the channel catfish is 10.7 mg/g (ppth). Analysis of Kepone in spot revealed tissue concentrations in the following descending order: brains, liver, gills, other components, and muscle. On the basis of percentage of total body burden the descending order is: other components, muscle, gills, brain, and liver.

A frequent observation made for persistent chemicals in nature is that there appears to be a stepwise increase in tissue concentration levels in different trophic levels of an ecosystem. This is due to higher trophic levels consuming lower trophic levels and thus accumulating the already bioconcentrated toxicant from the lower trophic level. The degree of bioaccumulation potential for Kepone was investigated in a study conducted by Bahner et al. (1977) discussed previously. The laboratory food chains investigated revealed a relatively low potential for bioaccumulation for many species with the exception of blue crab and polychaete worms. In all cases, the bioaccumulation was measurable but for most species did not seem to be a major factor in the magnification of the Kepone concentration in the biota. Thus, the data available on Kepone would suggest that the major source of magnification in the biota is bioconcentration rather than bioaccumulation.

This conclusion is supported by evidence on DDT gathered by Hamelink (1971). This investigator hypothesized that residue concentrations in different trophic levels of an aquatic food chain were a reflection of the amount retained by organisms of a trophic level as a result of bioconcentration and solubility differences acting through systems of exchange equilibria. The primary evidence usually used to demonstrate bioaccumulation is the stepwise increase of a compound like DDT with each step in the food chain. Hamelink demonstrated such stepwise increases in DDT in a pond system where complete, incomplete, and broken food chains were compared for bioaccumulation potential. The tissue levels observed indicated a stepwise increase in concentration of DDT regardless of the food chain system. The explanation for the results is based upon partition coefficients between two immiscible solvents, water, and lipid containing tissues. As noted earlier, lipids do not appear to be the key factor for Kepone concentration.

The amount of Kepone bioconcentrated and the rate at which it occurs is determined particularly by the solubility of Kepone in water, in tissue, and the difference between the two solubilities. The implication for Kepone is that anything which increases the solubility of Kepone in water or decreases the solubility of Kepone in tissues will decrease the amount of Kepone bioconcentrated. The overriding factor in determining the amount of Kepone dissolved in the water of the James River is the affinity of the sediments for Kepone. At the present time the Kepone situation in the James indicates that the sediments represent the massive source of Kepone which can be highly bioconcentrated by the biota for many years. Hamelink's hypothesis suggests that the sediment reservoir is in a dynamic state and anything which alters its interaction with the water may alter the degree of bioconcentration. If the sediments are altered or manipulated in a manner which reduces their relative affinity for Kepone the degree of bioconcentration will increase. Furthermore, the hypothesis indicates that bioconcentration and not bioaccumulation through the food chain is the mechanism which is important in determining the amount of Kepone that will get into the tissues of the James River biota other than the blue crab.

Biologists at the EPA Gulf Breeze Laboratory have reviewed all toxicological data to select acceptable ambient Kepone levels which will be safe to aquatic life. The approaches considered are summarized in Table VIII.5. Based on these results, the Gulf Breeze staff has recommended a protective water quality criterion of 0.008 μg/ℓ (ppb). This is believed to protect all species tested to date. It would be a difficult criterion to implement, however, since it is at detection limits, without the use of sophisticated sample concentration techniques. Fluctuating analytical results and the lack of use of these concentration techniques make it uncertain whether present levels in the James River exceed this limit. In general, Bailey Creek and Bay water do. A limit based solely on production of fish with tissue levels below the FDA limits would be 0.022 μg/ℓ (ppb). Only one sampling point on the James River (City Point) had water with Kepone in excess of this concentration. Yet, fin and shell fish tissue Kepone concentrations remain in excess of FDA limits. Hence, water criteria are either too high, or are not the limiting factor for uptake by fish.

The food and sediment concentration value recommended for use by the Gulf Breeze Staff is 0.015 μg/g (ppm) Kepone. This is based on a safety factor of 0.1 over food quality criterion based on chronic feed studies. There is no real justification for the 0.1 factor, but the consideration of desorption of Kepone from sediments brackets safe levels between 0.08 and 0.008 μg/g (ppm). In this context, the 0.015 μg/g (ppm) level appears to be of the right magnitude. Had the less protective water criteria of 0.02 μg/ℓ (ppb) (FDA considerations) been employed, the sediment criteria would have been 0.02-0.2 μg/g (ppm) Kepone. In either case, many sediments in the James River and most in the Hopewell area including Bailey Creek and Bay exceed these criteria. This could explain why fish tissues continue to exceed FDA limits while water levels do not exceed water criteria based on concentration in flesh to the FDA limit. In summary, it is currently concluded that no adverse ecological effects will occur if Kepone concentratons can be maintained below 0.008 μg/ℓ (ppb) in water and 0.015 μg/g (ppm) in sediments. These are conservative estimates and should protect all trophic levels in the estuary.

FOOD RELATIONS OF THE JAMES RIVER BIOTA

The importance of bioaccumulation through the James River food chain has been discussed previously in this report and will not be detailed here. The earlier discussion indicates that relative to bioconcentration, bioaccumulation is inefficient and does not represent a major source of Kepone transport in the ecosystem for most species. However, Kepone is a persistent compound and thus a discussion of food chain relationships is of interest.

Many of the James River species, particularly those of economic importance have been investigated with regard to their seasonal abundance, distribution, spawning activities, and catch data. Finfish studies occasionally report gut contents but these data are much more difficult to locate and are usually incomplete. In most cases where food organisms are mentioned, the topic is of a very secondary nature to the primary subject of the report or publication. In general, while many aspects of James River species have been studied, knowledge of their relationships to other trophic levels is poorly developed.

TABLE VIII.5. ALTERNATIVE CRITERIA FOR KEPONE LEVELS IN WATER AND SEDIMENT

Approach	Method	Criterion	Remarks
Water			
Use of Application Factor	Application factor 0.01 for persistent chemical, spot most sensitive species 6.6 μg/ℓ.	0.01 x 6.6 = 0.066 μg/ℓ	Does not reflect results of chronic tests with sheepshead minnows and mysids.
Maximum Acceptable Toxicant Concentration (MATC)	Results of recent chronic tests with mysids	0.008 μg/ℓ	This is conservative level protective of all species tested.
Concentration Required to Reach FDA Food Limits	Divide action level (0.3 μg/g fin and shell fish, 0.4 μg/g crab) by bioconcentration factors (13,500 for oysters, 10,000 myrids).	0.3 ÷ 13,500 = 0.02 μg/ℓ 0.4 ÷ 10,000 = 0.04 μg/ℓ	This level is close to those at which toxic effects have been observed, contradicts observations in the James River.
Food			
Food Quality Criteria	Use a safety factor (0.1) on the MATC calculated for food (0.15 μg/g crab)	0.1 x 0.15 = 0.015 μg/g in food	This is based on limited knowledge and refers to food only.
Sediment			
Food Chain Considerations	Sediment level should not exceed food quality level due to benthic uptake.	0.015 μg/g	Does not account for desorption of kepone to water.
Consideration of Desorption Potential and MATC in Water	Assume desorption rate of 0.001 - 0.0001 and MATC in water 0.000008 mg/ℓ	0.000008 ÷ 0.001 = 0.008 μg/g 0.000008 ÷ 0.0001 = 0.08 μg/g	Highly dependent on washout rate.

A simplified food-web relationship has been developed for the James River major species and is presented in Figure VIII.1. The finfish species displayed in this figure are those identified in Chapter VI as being the most abundant in the James River during various seasons. The majority of the gut content analysis information was taken from Hildebrand and Schroeder, 1972, with the remainder obtained from the other articles referenced here.

The simple food web that was developed suggests two important factors that are related to the environmental assessment of Kepone in the James River. One of the most important species in the food relationships of many finfish in the River is the decapod crustacean which fills in for the conspicuously absent mysid. As stated before, Neomysis americana provides a food base for many of the important species of fish and particularly during the juvenile stages of some of the migratory species in other nearby rivers.

Figure VIII.1 also illustrates the importance of the benthic community. A large portion of the finfish community is supported by the organisms living in or on the James River sediments. Many of these organisms are filter feeders and subsist upon the detritus and organic-laden silt which is the main Kepone carrier in the river sytem. Others are scavengers and obtain their food from materials deposited on the river bottom. Thus, they are in direct contact with the sediments.

THE ENVIRONMENTAL IMPACT OF FUTURE KEPONE CONTAMINATION

Laboratory studies have confirmed the ability of Kepone to produce acute and chronic effects in aquatic species. Analyses have also confirmed that migratory fish moving into the James River can accumulate Kepone in their tissue to levels above FDA limits in a period of days to weeks. Closure of the James to fishing as a result of this accumulation is the single impact in the natural environment which can be tied directly to Kepone contamination. Attributing other impacts on the James River ecosystem to Kepone is speculative at this point. Most prominent is dramatic reduction in the blue crab population (>90% between 1972 and 1975), a considerable decrease in juvenile alosins, and the apparent absence of mysids. Laboratory data are not available to identify the Kepone levels which are associated with three specific effects, but some indication can be found in a review of sublethal toxicity levels. Studies with blue crab have shown a decline in moulting when provided food containing 0.15 μg/g (ppm) Kepone. Since oysters can concentrate Kepone by a factor of 10,000, these food levels could be reached if water levels exceed 0.015 μg/ℓ (ppb). Growth of mysids and sheepshead minnows is retarded when these species are exposed to 0.072 μg/ℓ (ppb) and 0.080 μg/ℓ (ppb), respectively.

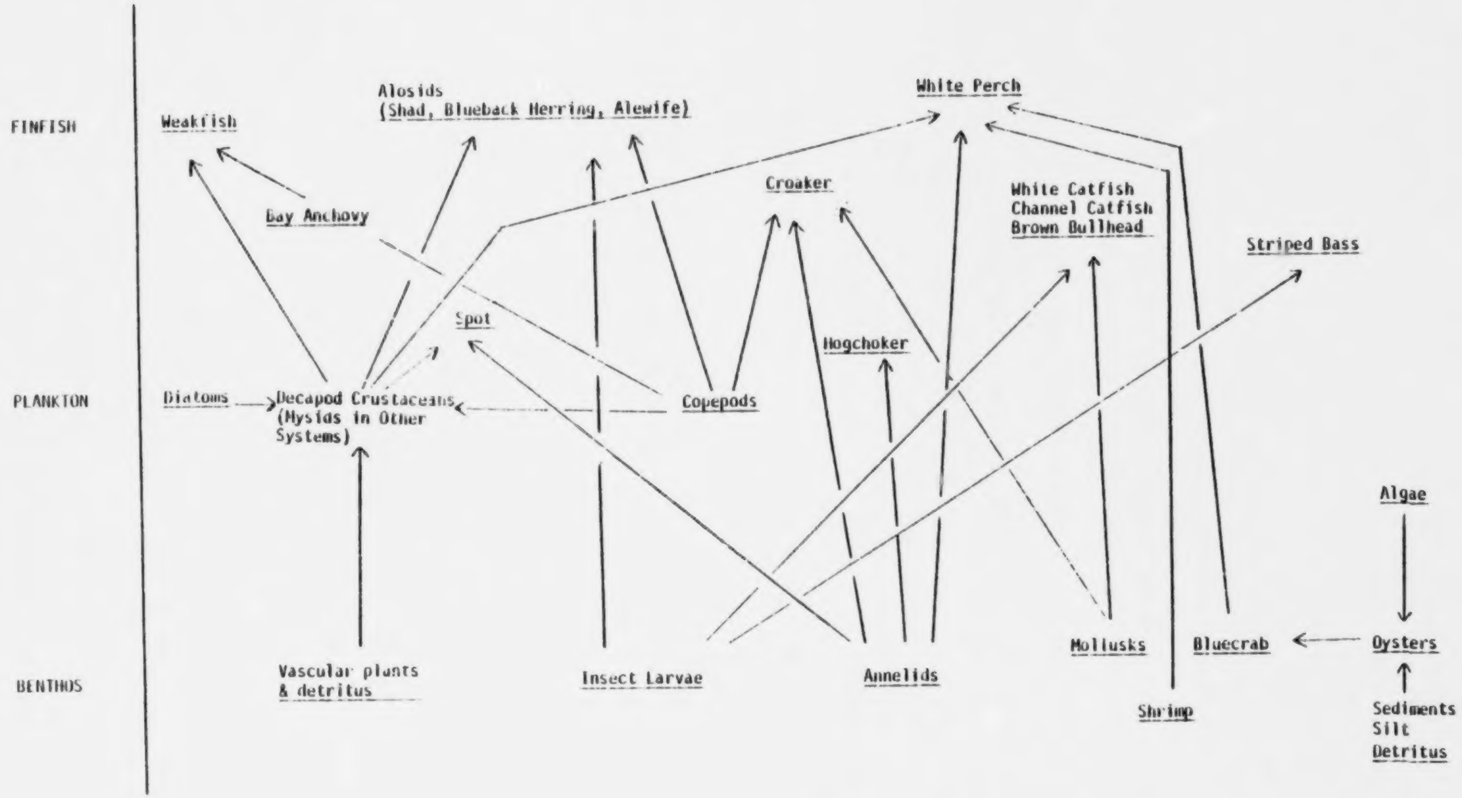
FINFISH
PLANKTON
BENTHOS
Weakfish
Alosids
(Shad, Blueback Herring, Alewife)
White Perch
Croaker
White Catfish
Channel Catfish
Brown Bullhead
Striped Bass
Bay Anchovy
Spot
Hogchoker
Diatoms
Decapod Crustaceans
(Mysids in Other Systems)
Copepods
Algae
Vascular plants
& detritus
Insect Larvae
Annelids
Mollusks
Bluecrab
Oysters
Shrimp
Sediments
Silt
Detritus

FIGURE VIII.1. Partial Food Web for Selected James River Species

Results of the mathematical modeling of the James River (see Chapter VII) indicate that soluble levels of Kepone currently range from 0.005 μg/ℓ at Burwell Bay to a high of 0.008 μg/ℓ (ppb) near the mouth of the Chickahominy River during low flows. Field data are restricted by levels of detection in this range and confirm only that soluble levels in the James River are only rarely above these concentrations. Both the predicted and observed values are below the concentrations at which sublethal effects have been noted, as discussed above. These data are very close to the recommended no effect criteria level of 0.008 μg/ℓ (ppb). Based on these criteria, direct effects to aquatic species do not appear to be occurring as a result of soluble Kepone in the James River. Similarly, bioconcentration factors reported for organism uptake from water do not account for the ability of fish and crabs to exceed FDA limits when exposed to James River water. Hence, the role of the sediments and food chain is very important in the effects noted to date.

This apparent lack of effects attributable to levels of dissolved Kepone can be expected to continue. Soluble Kepone is controlled by the concentration of Kepone in sediments and subsequent desorption. With all major sources of Kepone to the River eliminated, Kepone concentrations in sediment will decline over time and hence so will those of the water. This decline will be slow, however. It is estimated that only 76 to 170 kg (167 to 374 lb) of Kepone are transported past Burwell Bay each year by the River. An additional 10 to 100 kg (22 to 220 lb) of Kepone may leave the River in the tissues of migratory fish. These comprise only 1.4 to 3% of the total Kepone believed to lie in the sediments. As the concentrations decline, so will the rate of loss. Consequently, movement from the River will take decades to approach a zero state.

The overall loss process can be simplified to approximate a quantity of Kepone which is depleted by 2% of its remaining total each year, or:

$$Q = Q_o \ (0.98)^t$$

where

Q = the quantity of Kepone in sediment at any time t

Q_o = the original quantity of Kepone in sediment

Similarly, if a standard unit volume of sediment is considered, the expression can be replaced with:

$$C = C_o \ (0.98)^t$$

where

C = concentration of Kepone in sediment at time t

C_o = the original concentration of Kepone in sediment

This relation is delineated in Figure VIII.2 for concentrations of Kepone reported in various reaches of the James River. From these data and the above calculations, it would take over 200 years for sediments with 1 μg/g (ppm) Kepone to approach to the recommended safe level of 0.015 μg/g (ppm). Similarly it will take 175, 95, 60 and 14 years to reach that same level when initial concentrations are 0.5, 0.1, 0.05, and 0.02 μg/g (ppm) Kepone, respectively. These time periods represent maximum lengths of time since the relation assumes a completely mixed system when in fact movement below the turbidity maximum is better approximated as plug flow. Furthermore, no account is taken for dilution with uncontaminated sediments. Therefore, restoration by natural mechanisms is likely to occur more rapidly.

It should also be noted that depletion of bed sediment concentrations will not occur at an equal rate throughout the river. The turbidity maximum causes a buildup of Kepone at the salt wedge. This buildup is sustained as long as contaminated upstream sediments feed it.

It is clear that Kepone concentrations will remain highest in the area of the turbidity maximum near the mouth of the Chickahominy River. While fresh-water residents predominate in this segment of the James River, it serves as an important nursery area for the hogchoker, bay anchovy, alewife, blueback herring, and shad. White perch and striped bass also use this area for spawning and as a nursery. The Chickahominy River is the upstream boundary for blue crab and croaker.

Research on sublethal effects of Kepone to aquatic life has focused on soluble levels. Little is known about sublethal effects resulting from Kepone concentrations in sediments. As noted earlier, current soluble levels in the James River are believed too low to be responsible for direct effects on the ecosystem. Therefore, any impacts noted must be closely tied to sediment contamination. The vast majority of the river sediments below Richmond presently contain Kepone in excess of the 0.015 μg/g (ppm) level deemed safe.

The 0.015 μg/g (ppm) Kepone sediment level was selected on the basis of safe food limits for blue crabs and the observation that these food organisms can attain the same tissue concentrations as the sediments with which they are associated. This implies that if Kepone concentrations in sediments remain above 0.015 μg/g (ppm) continued impacts on the crab population can be anticipated.

The current concentrations in sediments are also responsible for keeping fish tissue above FDA limits. No quantitative relations have been developed to determine how low sediment concentrations would have to be taken to keep organism tissues below the limits. Suspended sediments in the lower James carry Kepone at concentrations in the tens of parts per billion. Hence, fish must be capable of concentrating Kepone by a factor of 10 over the suspended sediment. If suspended sediments originate as bed sediments, then fish tissue may exceed FDA limits if bed sediments have Kepone concentrations in excess of 0.03 μg/g (ppm). This is close to the 0.015 μg/g (ppm) recommended safe limit for sediments. Hence, fishing restrictions in the James River due to high Kepone residues in fish is likely to persist for many years as evidenced by Figure VIII.2.

Based on these considerations, it is projected that sublethal effects and tissue concentrations above current FDA limits will persist for a period of many years. Blue crabs and alosins are most likely to be impacted by these effects as they apparently have been in the past. The effects on the alosins may persist somewhat longer than those on blue crabs because of their use of the zone around the Chickahominy River which will sustain high Kepone concentrations for the longest time of any portion of the River.

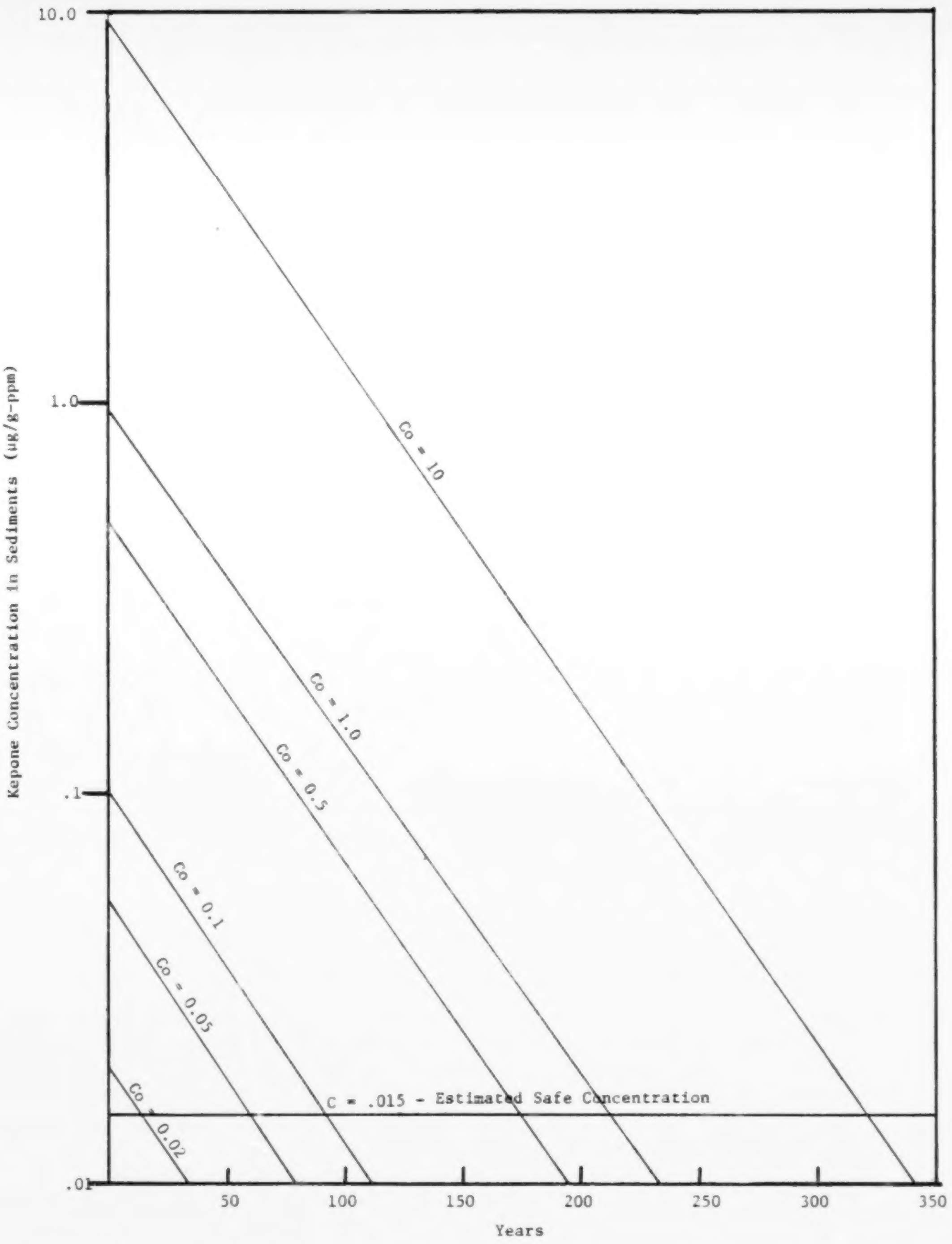

FIGURE VIII.2. Time Dependence of Kepone Contamination in Sediments

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CHAPTER IX - HOPEWELL ALTERNATIVES EVALUATION

SUMMARY

Content

Chapter IX describes methods for eliminating Kepone contamination from the terrestrial areas of Hopewell. It begins with the establishment of a set of example criteria that are used to delineate areas of potential cleanup activities. The scenario resulting from application of these working criteria would include mitigation activities at Nitrogen Park, a portion of the old Life Science plant site, the Kepone disposal lagoon, open spaces in the Station street neighborhood, and the marsh adjacent to the southeastern corner of the Hopewell landfill. Various techniques are presented that could address the Kepone contamination in these and other areas of Hopewell. Costs and environmental impacts of alternatives are compared, which leads to establishment of a comprehensive cleanup plan as dictated by the set of working criteria applied in this scenario. The final section of Chapter IX provides an overview of techniques available for destruction of Kepone residuals in the materials generated from cleanup activities.

Findings

- Current data on human and ecological dose response to Kepone levels in soil are insufficient to establish technical criteria for designating required cleanup actions in Hopewell.
- Potential techniques for mitigating the impacts of Kepone in surface soil include scraping or excavation, soil cover and seeding, lime treatment to accelerate leaching, amine accelerated photolysis, and the addition of synthetic soil amendments.
- Uncertainties concerning the effectiveness and environmental impact of lime treatment deem it an inadvisable mititgation alternative at this point.
- Tree cover inhibits the effectiveness of amine accelerated photolysis and synthetic soil amendments.
- Cost of excavating and drumming contaminated marsh sediment adjacent to the southeastern portion of the landfill is estimated to be $5,000.
- Covering Nitrogen Park with 5 cm (2 in.) of uncontaminated soil and reseeding would cost approximately $3,500.
- High-temperature incineration is an effective means of destroying harmful Kepone residuals.

INTRODUCTION

The complexity of interactions of Kepone with the environment in the Hopewell area along with a significant amount of missing information has hampered efforts to identify the cause-and-effect of current Kepone movement patterns. However, it is apparent that Kepone residuals persist and that they act as a continuing source of contamination to Bailey Bay and the James River. It is therefore important to evaluate alternatives available to eliminate these sources.

From the sampling and analysis work performed during recent studies, two continuing sources of Kepone movement to the River have been identified: (1) contaminated soil and (2) disposal sites. Prior to construction of the new regional sewage treatment plant, the Hopewell primary plant contributed a major portion of daily inputs to Bailey Bay. Total inputs, however, were in the tens of grams per day range. Subsequent opening of the regional plant and estimates of the total Kepone content of this source have reduced its importance as a source term. Before selecting and evaluating alternatives, both the objective of the restoration effort and the overall strategy to be employed in the selection process must be determined. A method of establishing criteria is presented in the following section to illustrate how this could be accomplished if sufficient data were available.

ESTABLISHMENT OF EXAMPLE CRITERIA

In general, the objective of restoration is to reduce Kepone migration and to reduce Kepone availability to organisms. Uncertainty over the impact of chronic low-level exposure makes it difficult to select quantitative criteria pursuant to the objective. One approach would be to assure that efforts are directed to maintain the effluent levels of 0.5 $\mu g/\ell$ (ppb) selected for discharges from the Hopewell sewage treatment plant. This effluent limitation was developed as a working guideline in April 1975, however, and does not reflect recent studies on the effect of Kepone on aquatic communities. Therefore, it may not agree with ambient water criteria currently recommended by the EPA Gulf Breeze Laboratory.

Alternately, criteria can be selected on the basis of present knowledge of dose-response relations. Laboratory data suggest that accumulation through the food web can lead to concentrations in fish above the action level if Kepone levels in water exceed 0.02 $\mu g/\ell$ (ppb) (see Chapter VIII). Consequently, total daily Kepone discharges must be kept below the level which would sustain these concentrations in the net daily outflow from Bailey Bay. The latter flow rate is roughly equivalent to the total daily inflow to the Bay as well as James River flow. From rainfall data for the

Bailey Creek drainage, the tributary input is an average of 190,000 m^3/day [close to 50 million gallons per day (MGD)]. The nearly 532,000 m^3/day (140 MGD) of industrial cooling waters discharged to Bailey Bay have not been included since they are withdrawn from the same general area and constitute a recycle rather than new input. Municipal inflows are minor. To this must be added the flow of the James River. To assure acceptable levels at all times, a low flow rate case was applied. During June 25-28, 1977 the flow at Cartersville was 51 m^3/sec (1800 cfs). This was a 20-year low flow and is adequate for the purposes here. Flow at City Point is generally 1.22 times that at Cartersville or 62 m^3/sec (2200 cfs) during the June 25-28, 1977 period. Hence, Kepone discharges must be kept below:

$$M = 0.02\ \mu g/\ell \times 5.4 \times 10^6\ m^3/day$$

$$= 2 \times 10^{-8}\ g/\ell \times 5.4 \times 10^9\ \ell/day$$

$$= 108\ g/day$$

Use of this rationale is somewhat moot at this point since, as is evident from Table V.16, identified inputs at this time are considerably below this level. Hence chronic stress is not likely from current Hopewell inputs.

At the same time Kepone outflows should also be controlled to ensure that no individual source exceeds levels which can lead to acute ecological damages. The lowest 96-hr LC_{50} reported to date is 6.6 μg/ℓ (ppb) for spot (see Table VII.1). This does not imply that any input with Kepone in excess of this level would sponsor acute effects, since dilution and dispersion in receiving waters must be considered. However, it serves as a working limit for the evaluation of mitigation alternatives performed here.

There is also concern for contaminated surface soils from the standpoint of direct public contact. It is assumed that open fields, parks, playgrounds, etc., with high levels of Kepone on the surface may endanger people who come in direct contact with the soil. In particular, even if contact is infrequent, there is a potential for allergic reactions and skin irritation. This is hypothetical to some extent since dose-response relations for direct contact have not been characterized.

Some data are available to give perspective on concentrations of Kepone which may cause harm in the environment. Female rats fed Kepone in their diet began to show significant effects on the size of the liver and kidneys at 5 to 10 μg/g (ppm) Kepone. At 10 μg/g (ppm) Kepone the females were also highly excitable. A value of 1.0 μg/g (ppm) was selected as the no effect level. Reproduction in mice has been affected by food levels of 10.0 μg/g (ppm) Kepone. Predaceous insects and anthropods are not (3 out of 4) affected by concentrations of 1 to 2 μg/g (ppm) in soil; however, birds display greater than 50% reduction in reproduction when fed 5 to 10 μg/g (ppm) (U.S. EPA, 1975a). Based on these results soils with greater than 10 μg/g (ppm) Kepone are addressed as candidates for elimination from public contact. Soils in the Hopewell area with the concentrations >10 μg/g (ppm) roughly coincide with areas producing runoff with Kepone in excess of 6.6 μg/g (ppm). This does not constitute a health criteria. Rather, it reflects a working standard employed for the work reported herein to focus attention for mitigation alternatives. Sites selected by these criteria should be considered as examples illustrating potential costs of restoration.

One final criterion is directed to deposits of Kepone. Any large quantity of unconfined Kepone in the environment should be isolated and confined to prevent future migration into the River. In this context, "large" would refer to any deposit of sufficient size to add significantly (10%) to current quantities of Kepone in James River. Hence, deposits of more than 1000 kg (2200 lb) should be addressed. In summary, in accordance with the example criteria, mitigation in Hopewell should be addressed to areas with runoff containing greater than 6.6 μg/ℓ (ppb) Kepone, surface soils with greater than 10 μg/g (ppm) Kepone and subsurface deposits with more than 1000 kg (2200 lb) of Kepone.

The strategy for achieving this objective is based first on an attempt to collect and destroy Kepone residuals which exceed criteria limits. The alternatives should at least intercept inflows or prevent public contact. Once alternatives have been identified which can satisfy these objectives, selection will be based on cost and potential impact considerations. A discussion of individual alternatives follows.

CONTAMINATED SOIL

From the results of field sampling and analysis in Hopewell it is apparent that the surface layers of soil are a repository for Kepone at this time. Based on measurements in the top 2.5 cm (1 in.) in the area bounded by Bailey Creek, the James River, the Appomattox River and the southern city limits of Hopewell (approximately 11 mi^2), it is estimated that 45 to 450 kg (100 to 1000 lb) of Kepone presently exist in surface soils. The bulk of this is distributed in a radial fashion from the old Life Science Products Company site with concentrations of Kepone decreasing with distance.

Laboratory and field data suggest that this contamination is subject to movement both outward and downward. The outward movement is driven by runoff which in the plant site area has been found to contain up to 687 μg/ℓ (ppb) Kepone. In subsequent leach tests with contaminated soil from the Nitrogen Park area, it was determined that natural soils containing 9 to 200 μg/g (ppm) yield 112 to 604 μg/ℓ (ppb) when contacted with distilled water. This is far in excess of levels which would be predicted from partition coefficients between sediments and water, and suggests that much of the Kepone in Hopewell soils is particulate Kepone from atmospheric deposition rather than Kepone bound to soil particles through sorption. Hence, runoff may dissolve particulate Kepone and/or suspended fine particles without carrying larger soil particles to transport Kepone horizontally. Kepone will be present even if runoff does not occur at high scour velocities. Ultimately, the soluble Kepone will equilibrate with nearby solids.

Movement downward results from percolation, which appears to be both slower and less prevalent than horizontal movement as a result of the affinity between Kepone and particulate matter in soil. Kepone's particulate affinity is similar to that noted in aquatic sediments in the James River system. To quantify the equilibrium levels expected, samples of top soil and deeper soil from the Hopewell area were shaken overnight in a Kepone solution. It was determined that Kepone partitions with soils from Hopewell at a level of 3 to 6 x 10^{-3} (concentration in water to concentration in soil). The lower partition values are found in deeper soils. Hence, Kepone movement is retarded more at the surface than in the lower layers of soil. Evidence that percolation has occurred was found in cores from two wells [Nitrogen Park — Kepone at 6.1 m (20 ft) and north lagoon well — Kepone at 3.1 m (10 ft)] in a smaller (25 cm) core at Nitrogen Park, in ground water in scattered wells around the Hopewell area, and in deep cores from the Pebbled Ammonium Nitrate Plant site. At Nitrogen Park, runoff water flows northwest until blocked off by fill for the road. At that point the water becomes ponded in a low marshy area where percolation and evaporation are the only outlets for water. At the lagoon well the percolation may reflect seepage from the lagoon itself.

Based on data provided in Chapter V, there are four areas in Hopewell which meet surface soil and runoff criteria outside of disposal sites: the former Life Science Products plant, Nitrogen Park, open areas in the Station Street neighborhood, and the Allied Semi-Works plant site. The Allied Semi-Works plant was found to have ponded water containing 48.3 μg/ℓ (ppb) shortly after a storm. Drainage from the site (runoff) carried only 3.38 μg/ℓ (ppb). Associated soil levels were 11.8 and 23.2 μg/ℓ (ppm) in the area surrounding the site. However, this site is removed from further discussion since Allied Chemical is currently formulating plans in conjunction with the Commonwealth of Virginia to eliminate this contamination.

The elimination of contaminated soil as a source can be accomplished by either of two approaches: (1) source elimination or (2) interdiction of horizontal and downward routes of movement.

Source Elimination

Methods of source elimination are in general preferable to approaches which would stop transport since these approaches isolate but do not remove the hazard. Methods available for source elimination are relatively limited. The simplest approach would be to physically remove contaminated soil and dispose of it. This would involve scraping contaminated layers of soil where Kepone has remained near the surface, an approach already taken at the Life Science Products plant. In areas where contamination is much deeper, excavation would be required. To evaluate this approach, candidate areas have been selected with use of the working criteria. It was also necessary to select a means and place for disposal or isolation of these soils.

In the estimation of costs for soil scraping, costs were compared to site preparation work involving clearing and grubbing. It was necessary to assume that there was minimal vegetative cover, including light brush and few small trees. EPA reference material was used to develop the study estimate (Pound et al., 1975). The EPA estimate was based upon an EPA Sewer Construction Cost Index of 194.2. The revised 1977 index value is 288.0 and this figure was used to update costs.

Costs for soil scraping are estimated to be $1,100 per acre using bulldozer and blade type equipment at sites 10 acres or greater in size. This estimate presumes that debris will be disposed on site. If offsite disposal is required, the cost estimate should be doubled to $2,200 per acre. The higher estimate is most appropriate since Kepone-contaminated soil would have to be removed to a secure area and most sites are smaller than the minimum 10 acres upon which the cost relation is based.

In areas where significant Kepone can be found at depth, excavation may be needed. Local costs in the Hopewell area average $2.10 to 2.50/yd^3 for shallow excavation (<5 ft) and $2.50 to 3.00/yd^3 for deeper work. The high end of these ranges was used. Cost estimates for soil removal at prospective sites are detailed in Table IX.1. Associated costs for disposal must be added, and are considered in the Subsequent Appraisal Section.

TABLE IX.1. COST OF SOIL REMOVAL AT SELECTED SITES

Site	Area (acres)	Cost, Scraping ($)
Nitrogen Park	1	2,200
Life Science Products	0.125	300
Station Street Neighborhood	1	2,200

Kepone could also be minimized in runoff by accelerating dissolution with a caustic wash. Kepone is more soluble in alkaline solutions and therefore would desorb more readily from soils if alkaline waters are employed. Subsequent runoff would have to be collected prior to reaching natural waters. In the Life Science Products plant area, the combined storm sewer system could be used for collection and wash could be neutralized at the old treatment plant. This would greatly reduce levels of soluble Kepone and allow it to concentrate in sludges that are already contaminated.

A related approach involves solid lime placed on the soil surface. Natural precipitation would solubilize the lime and Kepone which then could be trapped in the storm runoff. That which percolated would move the Kepone to the vadose zone where natural attenuation mechanisms should hold it. This procedure would have a similar effect to covering the Kepone with uncontaminated soil. Dosing with lime would have to be carefully performed to assure that any excess would be neutralized by the soil prior to carrying the Kepone to underlying aquifers. Runoff could also be accelerated without chemicals simply by irrigating contaminated areas to rinse surface layers thoroughly. Since solubility levels are extremely low, this is likely to be a slow process.

The cost of caustic leaching will largely reflect the amount of chemical required and the number of retention dikes needed to maintain control. Laboratory tests with loam topsoil from the Hopewell area indicate that a dose of 0.8% (on a dry weight basis) is required to bring the soil solution pH to 12 where leachate levels of Kepone will exceed 6 $\mu g/\ell$ (ppb) (see Table IV.2). The total quantity of lime required for each site and associated costs are presented in Table IX.2. The cost for control is based on \$100 per day rental fee for pumps and \$30 per yd^3 for earth fill. Lime is calculated at \$37 per ton and application is assumed to include discing at \$100 per acre. The costs reflect treatment of the surface only. Caustic rinses will not be effective in removing deposits of Kepone below the surface. Use of sodium hydroxide solution in place of lime is estimated to cost twice as much.

TABLE IX.2. ESTIMATED COST FOR LIME TREATMENT OF SOILS AND SUBSEQUENT RUNOFF CONTROL

Site	Quantity of Soil (Top 1 in.) (lb)	Cost of Lime ($)	Control Costs($)	Total Costs ($)
Nitrogen Park	437,500	165	200*	365
Life Science Products	55,000	20	---**	20
Station Street Neighborhood	437,500	165	---**	165

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*Assumes runoff can be pumped from the marshy holding area to a nearby manhole during two storms.

**Assumes runoff will be intercepted by existing storm sewer.

While physical removal is the simplest approach in concept, it is expensive and involves large volumes of residuals requiring disposal. For these reasons, approaches to in situ degradation may be preferable. Such an approach generally requires the identification of agents which will oxidize the Kepone in place without leaving equally harmful residues. As noted previously, Kepone appears resistant to natural chemical, photochemical and biochemical attack. Very specific chemicals and/or very harsh conditions are required to initiate degradation. In the review of options for the removal and/or destruction of Kepone, several such harsh oxidation schemes were evaluated. Chlorine dioxide and ozone were found to be quite ineffectual when applied individually to solutions of Kepone. Ozone in conjunction with ultraviolet radiation was effective with contact of 45 min and more. This approach, however, is not readily applied to soils in situ since it is difficult to maintain the contact required. Further details on mitigation effectiveness can be found in Chapter X.

Promising results were obtained with γ irradiation and photolysis in the presence of amines. The γ radiation was not considered further because destruction was not complete and doses were considered high for use in public areas. The amine photolysis appears more attractive. Preliminary screening has revealed that in the presence of ethylenediamine, Kepone is subject to photochemical attack from sunlight. When contaminated sediments were sprayed with ethylenediamine at the rate of 10% and placed in direct sunlight, 30% of the Kepone was oxidized after 10 days of outdoor exposure. The costs for applying a similar dose to surface soils (top 1 in.) in Hopewell are estimated in Table IX.3. This is based on a current cost of $0.805 per lb for ethylenediamine and an application cost of $500/acre.

TABLE IX.3. COST OF AMINE ACCELERATED PHOTOLYSIS OF KEPONE

Site	Surface Area (acres)	Cost
Nitrogen Park	1	4,000
Life Science Products	0.125	500
Station Street Neighborhood	1	4,000

Interdiction of Transport Routes and Elimination of Contact

Should it prove economically or technically infeasible to remove all Kepone-contaminated soil, it is still possible to eliminate the important routes of transport or contact and, in so doing, effectively isolate the Kepone. In the case of surface soils, this would mean preventing the spread of soluble Kepone by runoff waters and preventing human and biota contact.

One approach would be to cover present surfaces with a layer of sufficient depth to prevent runoff from picking up Kepone. This would also prevent direct contact with high concentrations. Coverings could range from natural soils to soil amendments or polymeric coatings such as Dowell M179 (see Chapter X). These types of approaches have been demonstrated for erosion control in a variety of locations. Partial covering could also be achieved by planting grasses or other ground cover plants. Comparison of adjacent surface soils in Nitrogen Park has revealed significantly higher Kepone levels in grass-covered locations than in bare soil. This may reflect an ability to retain Kepone deposited from the atmosphere. In either event, plant cover appears to reduce mobility. It does not, however, reduce the potential hazards of direct contact.

The costs associated with these options are compared in Table IX.4. Costs for soil addition and seeding are based on applications of 2 in. of soil at \$538/acre in., 5 lb of seed/1000 ft^2 at \$435/acre, a hauling distance of 20 miles at \$3.50/ton, and spreading costs of \$200/acre in.

TABLE IX.4. ESTIMATED COSTS OF AMENDING SURFACE SOILS IN CONTAMINATED AREAS

Site	Area to be Treated (acres)	Cost ($) Soil Cover (2 in.) and Seeding	Cost ($) Synthetic Amendment
Nitrogen Park	1	3,500	—
Life Science Products	0.125	440	1,250
Station Street Neighborhood	1	3,500	10,000

Costs for application of Dowell M179 are based on an application rate of 60 tons per acre at a delivered cost of \$158 per ton for rail car shipments. An application cost of \$100/acre is assumed based on use of conventional discing. When these unit costs are employed, the total cost for application of a soil amendment is equivalent to that for applying 6 in. of soil and reseeding. The soil amendment approach, however, cannot be used in areas with heavy vegetative cover since the plant life will reduce the integrity of the seal. This would be the case in the Nitrogen Park and Station Street neighborhood areas.

These alternatives are untested in the context offered here and require further evaluation and possible field testing prior to implementation. Comparative test plots using candidate soil covers would be helpful in generating quantitative data.

CONTAMINATED SEWERLINES

Periodic analysis of sewage from the Hopewell area has revealed continuing levels of Kepone in domestic wastewaters. Simultaneous sampling of major trunk lines in the city further revealed that contamination was not localized in the Station Street area where the Life Science Products plant operated, but was widespread throughout the city. Similarly, slime growth from sewer pipe walls and wet wells displayed a significant level of Kepone. It is hypothesized that this pool of Kepone feeds the continuing Kepone concentrations in the wastewater through a process of slow desorption. For instance, with a nominal partitioning of 5×10^{-4} (water: solids), average slime levels of 0.4 μg/g (ppm) are all that is necessary to sustain 0.2 μg/ℓ (ppb) Kepone in the wastewater. As noted earlier, at this rate all Kepone in the sewer system would have been depleted long ago if continuing input did not exist over and above the less than 1 lb estimated in the trunk lines, which serve as a long-term, low-level source of Kepone.

Elimination of this long-term, low-level source would require an extensive sewer cleaning effort directed both at the growth on the walls and at residual organic matter in wet wells or other holding areas. A similar effort was conducted on portions of the Hopewell system near the Life Science Products site during initial cleanup efforts. The effectiveness of that action is difficult to assess since subsequent analysis suggests that highly contaminated runoff (>600 μg/ℓ-ppb) has returned the level of Kepone in sewer organic matter to near previous levels.

Sewer cleaning is typically performed with mechanical or hydraulic devices to physically dislodge solid matter from pipe walls. Because of Kepone's specific chemical properties, a high strength caustic flush may also be effective. In this case, provisions would be needed to neutralize the Kepone-bearing waste solution at the old sewage treatment plant prior to routing to the new regional secondary plant. This would protect the biological activity in the new plant, and reduce soluble Kepone for management with the sludge fraction.

If it is assumed that the elevated pH must be maintained for 1 day, sufficient caustic will be required to produce 11,360 m^3 (3 million gal) having a pH of 12. Assuming relatively high concentrations of magnesium (20 mg/ℓ-m) and calcium (40 mg/ℓ-ppm) this would mean a maximum solution strength of 0.015 molar NaOH or roughly 6.8 metric tons (7.5 tons). Caustic would be supplied from tanks of 50% solution and metered into mainlines and trunks over a 24-hr period. Sulfuric acid would be applied at the sewage treatment plant to reestablish a neutral pH. Total cost for chemicals would be $4500. Alternatively, the bacterial growths themselves could be attacked directly with an oxidant such as chlorine or sodium hypochlorite.

Sewer cleaning costs depend upon many considerations. Some of the criteria involved are shown in Table IX.5. It is apparent from this list that costs can be highly site specific. This would account for the broad range of costs reported in a national survey on sewer rehabilitation shown in Table IX.6 (EPA, 1975).

TABLE IX.5. SEWER CLEANING COST CRITERIA (EPA, 1975)

Access to manholes

Manhole conditions

Type of manhole construction

Size of manholes

Depth of sewer

Depth of flow

Depth of deposition

Type of deposition

Pipe size

Structural condition of sewer

Length of manhole section

Intruding building sewers

Requirement for transportation and disposal of material removed from sewer

Distance to disposal site

Traffic control requirement

Availability of water

Degree of root intrusion

Random vs. successive manhole section

Weather condition

Mobilization distance

Availability and cost of labor

TABLE IX.6. SEWER CLEANING COSTS (EPA, 1975)

Size (in.)	Cost ($/foot)
6	0.30 - 1.10
8	0.25 - 0.90
10	0.30 - 1.30
12	0.35 - 1.70
15	0.40 - 2.10
18	0.50 - 2.25
21	0.70 - 3.50
24	0.80 - 4.25
30	1.15 - 5.50
36	1.45 - 6.80

Realistic cost estimates have been developed from the EPA Handbook (EPA, 1975). Data from Table IX.6 are plotted in Figure IX.1. A curve of best fit for average cleaning costs was developed in the following manner. An arithmetical average was determined for each range of given pipe diameters. Then a linear regression analysis of the averages was performed. The curve of best fit on Figure IX.1 is the result of this analysis. The equation of the resulting line is:

$$C = 0.115D - 0.311$$

where:

C = sewer cleaning cost in dollars per foot
D = pipe diameter in inches.

This equation is a fair representation of the costs involved in cleaning segments of the Hopewell sewer system, and includes the cost of residue disposal. The costs do not include any additional costs required to account for the contaminated nature of the residues.

A detailed breakdown of trunk line diameters and lengths for the Hopewell sewer system is not available. City routing maps and design specifications were lost in a fire and comprehensive information is lacking. Therefore, it was necessary to estimate pipe dimensions using standard design practices and knowledge of the flow between pump stations. The resulting estimates of sewer dimensions and associated cleaning costs are given in Table IX.7.

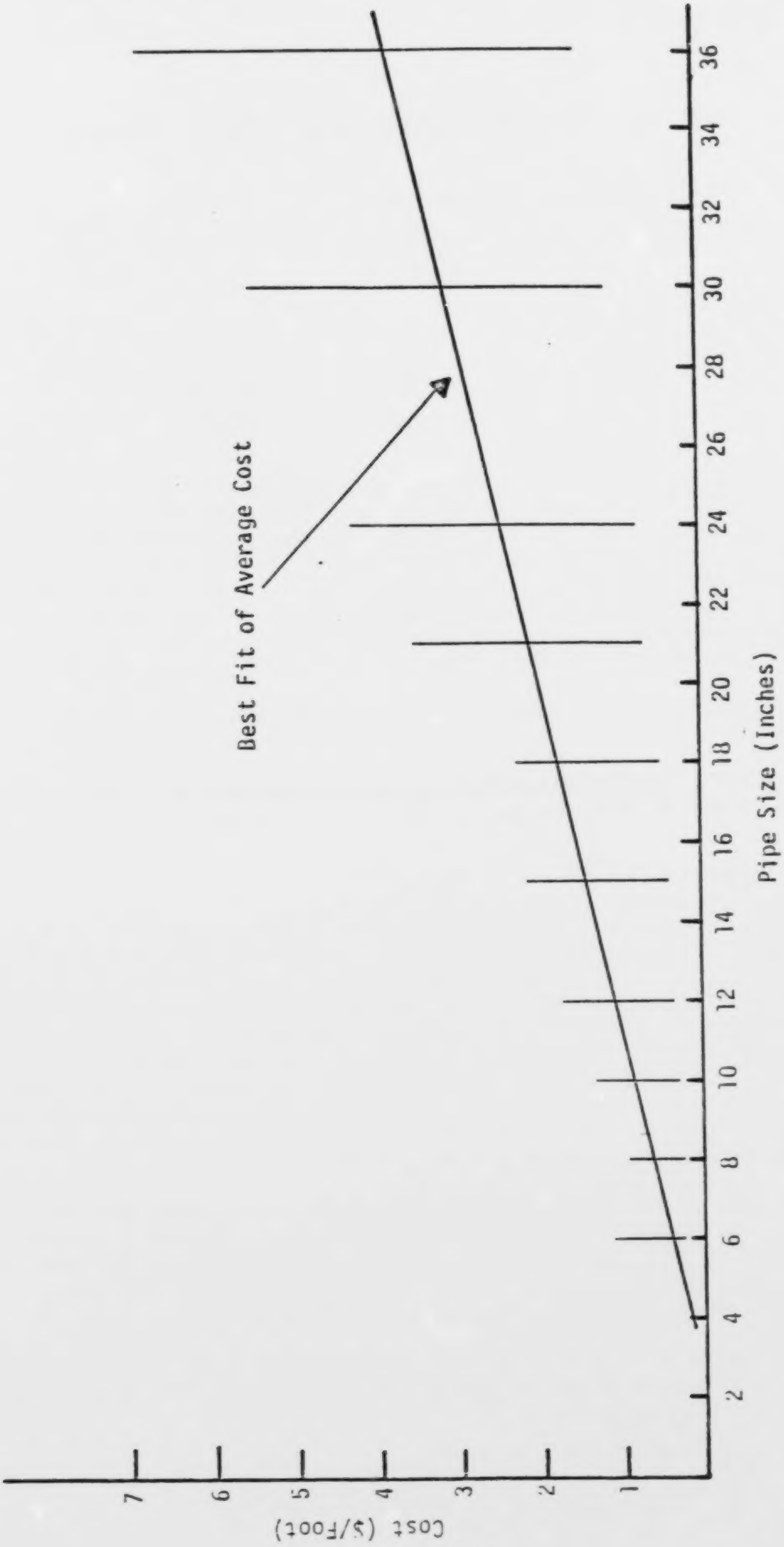

FIGURE IX.1. Sewer Cleaning Costs

TABLE IX.7. COST OF CLEANING SEWER LINES IN HOPEWELL

Pipe Diameter (in.)	Pipe Length (ft)	Cost of Cleaning ($)
18	18,700	33,700
24	1,800	4,500
32	2,400	8,200
	Total	$46,400

It is noteworthy that the single area of Hopewell sewered by combined storm sewers is the Station Street segment containing the old Life Science Products plant. Recent EPA efforts have focused on persuading the city of Hopewell to separate this last combined sewer and discharge storm runoff directly to the James River. However, analysis of storm runoff in and around the old plant site reveals high levels of Kepone contamination (50 to 687 μg/ℓ-ppb). These are greatly in excess of the 6.6 μg/ℓ (ppb) criteria. Therefore, the following two options should be considered:

1. Separation should be delayed until Kepone levels are reduced in runoff.
2. Separation should be accompanied by construction of a facility to remove Kepone from the runoff prior to discharge.

DISPOSAL SITES AND LAGOON

As noted previously, there are several discrete deposits of Kepone and Kepone-laden wastes in the Hopewell area. These may constitute additional sources of Kepone to the James River. One of these deposits is the Kepone sewage sludge lagoon constructed at the old sewage treatment plant in 1975. Data developed to date indicate that this lagoon may be leaking Kepone to Bailey Creek through subsurface leachate. Given sufficient time, a significant portion of the estimated 100 kg (220 lb) of Kepone in the lagoon could find its way to the creek. While this amount is too small to meet the total quantity criteria and is not subject to direct public contact, the seeps generated through percolation exceed all runoff criteria.

The most obvious alternative for rectifying a leakage problem would be to remove the lagoon water and destroy the Kepone. However, current plans will not provide an acceptable means of Kepone destruction for several years. Consequently, physical removal will result in little more than transfer of the sludge to a new lined site (EPA, 1975).

A second option is to eliminate the transport routes of the Kepone. Current water levels in the lagoon are a direct reflection of precipitation and runoff piped from the barrel storage area at the treatment plant to the lagoon. An alternative for eliminating the possible lagoon seepage is to dewater the lagoon and cover it to prevent future inputs of water. This should isolate the Kepone until facilities are available to destroy it.

Future percolation can be prevented with grouting or other sealants, but eliminating the entrance of water with an over cover would minimize the need for subsurface sealing. Runoff from the barrel storage area will have to be released, but visual inspection should be adequate to guard against leaking drums. The cost of sealing dewatered lagoons was regarded as being similar to costs for lining new lagoons or ponds. EPA reference material was the prime source for developing estimates (Pound et al., 1975).

As with the soil scraping estimates, the EPA Sewer Construction Cost Index was updated from 194.2 to 288.0. Adjusted EPA data were plotted graphically and a linear regression analysis performed. The resulting linear equation is shown in Table IX.8. Note that the factor "m" in the equation is a function of the type of sealing material. If a material other than those shown (for which adjustment factors are listed) is used, then "m" should be modified accordingly.

TABLE IX.8. LAGOON SEALING COST EQUATION

$$L = m \left[7121.9\ (V) + 1415.6 \right]$$

where:

L = Cost of lagoon sealing in dollars

m = Materials adjustment factor as follows:

bentonite = 0.86

asphaltic = 1.00

PVC (10 mil with soil blanket) = 1.21

soil cement = 1.21

Petromet = 1.24

Butyl neoprene (30 mil) = 1.97

V = Storage volume in millions of gallons

This modification can be made by plotting materials costs and normalizing to asphaltic material which has an "m" factor of 1. Alternatively, ratios to other known material costs can be made.

Based on these data, costs for sealing the lagoon against precipitation are estimated at $15,000 per 10 mil PVC sheeting and $24,000 for 30 mil butyl neoprene. Costs for sealing the bottom or grouting are summarized in Table IX.9.

TABLE IX.9. COST SUMMARY FOR SEALING OR GROUTING THE DISPOSAL LAGOON

Mode	Cost ($)
Surface Seal	
PVC (10 mil)	15,000
Butyl Neoprene (30 mil)	24,000
Bottom Seal	
Bentonite	10,000
Asphalt	12,000
Soil Cement	15,000
Petromat	15,000

Two specific disposal sites were studied as reservoirs of residual Kepone in addition to the lagoon. These are the Pebbled Ammonium Nitrate (PAN) plant and the landfill. The PAN site was found to contain only a small volume of Kepone spread through an extensive and deep pattern. The total quantity is less than the working mitigation criteria of 1000 kg (2200 lb). Runoff levels leaving the site are also below the cleanup criteria. Only a few, isolated surface soil samples had Kepone concentrations in excess of 10 μg/g (ppm), with the high soil concentrations being at subsurface levels. Consequently, the PAN site does not meet any of the mitigation criteria.

In contrast, the marsh below the bulk discharge area in the landfill exceeds the total quantity criteria. Over 1350 kg (3000 lb) of Kepone have been found in a 1012 m^2 (0.25 acre) area to a depth of 10 cm (4 in.). The area has been shown to produce high concentrations of Kepone in runoff and includes surface sediments with over 3.5% Kepone. Hence, mitigation would be considered in accordance with the sample criteria.

The heavy trees in the area and swampy consistency of sediments rule out scraping, whereas a mode of excavation would be more acceptable. Excavation could range from a dragline operation to manual removal. As noted earlier, shallow excavation costs $2.10 to 2.50/$yd^3$ in the Hopewell area. Under these adverse conditions, the costs could double to \$5.00/yd^3. At that rate, the total cost of mitigation at the landfill would run to:

$$\$5.00/\text{yd}^3 \times 140\ \text{yd}^3 = \$700.$$

APPRAISAL

There are several options available for mitigation of Kepone residuals in the Hopewell area in addition to the no action alternative. Costs differ between alternatives. Efficacy differs with the site of application. It is therefore necessary to look at the options in the context of each site and select the best on a case-by-case basis. The following discussion focuses on identifying the optimal alternative for each site and assessing associated environmental impacts.

Nitrogen Park

Analysis of soil samples from Nitrogen Park has revealed significant levels of Kepone in surface layers to a depth of 2.5 cm (1 in.). Simultaneous analysis of runoff waters verified the transport of Kepone from the soil surface. However, the present topographic configuration in that area does not allow for movement of the runoff down Poythress Run. Instead, it collects in a low swampy area and dissipates through evaporation and percolation. Hence, the Kepone in Nitrogen Park is of concern from the standpoint of direct contact with the soil and potential contamination of ground water. Historical well data (Table III.3) reveal variable concentrations of Kepone in the underlying local aquifer with a maximum level of 0.08 μg/ℓ (ppb) reported.

The alternatives evaluated and cost estimates for amelioration of this contamination are summarized in Table IX.10. The least expensive option is the use of lime to accelerate Kepone desorption in runoff. However, there is no means of assessing the effectiveness of this approach and potential effects on existing grass and trees could be severe. The uncertainties dictate against this alternative. Scraping is not feasible in the Nitrogen Park area because of the tree cover.

TABLE IX.10. COST SUMMARY FOR NITROGEN PARK ALTERNATIVES

Alternative	Cost (\$)
Lime Treatment	365
Scraping	2,200
Soil Cover and Seeding	3,500
Amine Accelerated Photolysis	4,000
Synthetic Amendment	10,000

The alternative of choice is therefore the addition of 5.1 cm (2 in.) of uncontaminated soil and replanting of grass. This will eliminate direct contact for the public with the contaminated soil and minimize uptake of Kepone in runoff. If clay-type soils are utilized, percolation will be minimized. Vertical distribution studies revealed an order of magnitude reduction in Kepone concentration of natural soils between the 1- and 2-in. levels. Upward migration would be expected to be less effective than the downward percolation reflected by these data. The amine photolysis alternative is associated with similar costs, but uncertainty about effectiveness and unknown ecological effects dictate against its use as this time. Photodecomposition may also be retarded as a result of the tree cover.

Other than minimal effects of noise and dust during application, no adverse impacts are associated with the application of a soil covering to contaminated areas. However, it is important to consider potential effects on ground-water quality of leaving Kepone residuals in place. As noted earlier, the occurrence of Kepone in a nearby monitoring well has been reported as transient and low level in nature. Hence, to date, soil attenuation has prevented any major ground-water quality impacts. Use of clay soils for the covering process should continue to minimize ground-water impact potential.

Life Science Products

The Life Science Products plant site area has been cleaned once during the shut-down activities. However, recent sampling has revealed that a portion (400 m^2) of the site was not sufficiently cleaned and currently maintains a high amount of Kepone (1535 μg/g-ppm). Additionally, runoff from the site has been found to contain 687 μg/ℓ (ppb) Kepone. Consequently, the site has been considered for additional mitigating activities. Costs for alternatives considered are summarized in Table IX.11.

TABLE IX.11. COST SUMMARY FOR LIFE SCIENCE PRODUCTS SITE ALTERNATIVES

Alternative	Cost ($)
Lime Treatment	20
Scraping	300
Soil Cover and Seeding	440
Amine Accelerated Photolysis	500
Synthetic Amendment	1250

As noted earlier, uncertainties about the effectiveness of lime treatment and potentially harmful impacts override the cost advantages of this alternative. Therefore, scraping is deemed optimal. The contaminated area does not have vegetative cover and consequently is well suited to scraping. The impact implications of soil removal are discussed in the next section. The estimated 28 m^3 (1000 ft^3) of contaminated soil could be stored in the present disposal lagoon or sealed in industrial drums. Since the latter option offers greater flexibility in the future, it is employed here for the purposes of cost estimation. An estimated 150 drums would be required. This would add $750 (assuming used 55-gal drums are available at $5 each) to the overall cost of mitigation.

A discussion of potential impacts associated with the scraping alternative is provided in the following section.

Station Street Neighborhood

The land around the Cavalier Ice Plant, Norfolk and Western Railroad, and Hopewell News facilities has been found to have concentrations of Kepone in surface soils in the range 10 to 1000 µg/g (ppm). This exceeds the surface soil level employed as a working criteria for areas where public contact occurs. A summary of mitigation costs is presented in Table IX.12. It is clear that lime treatment is the least expensive option. Once again, the uncertainty concerning effectiveness and side effects dictates against implementation. The scraping option appears most viable for these open spaces.

TABLE IX.12. COST SUMMARY FOR STATION STREET NEIGHBORHOOD ALTERNATIVES

Alternative	Cost($)
Lime Treatment	165
Scraping	2,200
Soil Cover and Seeding	3,500
Amine Accelerated Photolysis	4,000
Synthetic Amendment	10,000

With respect to anticipated impacts, it is apparent that cleanup of Kepone surface contaminated soils requires some environmental management precautions. The areas of major concern are associated with minimizing the movement of Kepone into the environment. Lack of control can result in increased atmospheric suspension and increased land and water concentration levels.

Releases to the atmosphere can result from scraping and loading transportation, and unloading of contaminated soils. Sources of contamination are from dust, spillage, and wind suspension of loosened soil materials. It is important that fugitive dust be minimized by wetting and covering unstabilized materials.

It is suspected that impact resulting in release of Kepone could come from lack of care in the scraping operation. Overfilling of scrapers and spillage of unconsolidated materials can result in land and runoff contamination. Transporting vehicles need to be covered enroute and care must be exercised in unloading vehicles to prevent dust release and spillage.

The contaminated spoil can have various impacts on the environment but the primary concern is the containment of Kepone to minimize its redistribution to air, land, and water. Certain control measures will need to be implemented to minimize Kepone losses depending on type of placement. Losses to the atmosphere can be minimized by placing a permanent covering over the spoils. The covering should also prevent infiltration of precipitation. Losses to ground water can be minimized by bottom sealing of the spoils or placing them in an area of minimum ground-water flow. The Kepone lagoon appears to be a prime candidate for spoils containment. There is presently sufficient volume for the estimated 426 m^3 (15,000 ft^3) of contaminated soil which would be removed from the Station Street neighborhood. However, the soils to be scraped are not sufficiently contaminated to warrant incineration along with the contents of the lagoon. The major reason for their removal is to eliminate public contact. Consequently, burial at the landfill would suffice. The total quantity of Kepone residuals in this soil is smaller than the working guidelines, so the buried residues would not create a new problem. However, care should be taken to select higher ground and surround the contaminated soils with clay materials. This will minimize potential future problems from runoff and leachate.

No particular health impacts have been identified with the disposal option, providing fugitive dusts are controlled, the contaminated spoils are properly managed, and workers wear protective clothing and masks. This management alternative appears quite feasible and effective with minimal short- and long-term impacts to a productive environment.

Landfill

As noted in Chapter V, the marsh below the bulk discharge area of the Hopewell landfill has been found to contain over 1350 kg (3000 lb) of Kepone. The only feasible means of addressing this deposit is removal. Excavation will be hampered by periodic flooding during high tide and the extensive tree growth in the area. Manual removal may be the most feasible alternative under these circumstances. In either event, the costs will be higher than normal for excavation.

Sediments in this area are contaminated to levels in excess of 3.5% Kepone. Hence, destruction of removed soils is warranted. Since placement of these residuals in the lagoon could aggravate existing leakage problems, drummed storage prior to incineration is appropriate. This will require approximately 500 drums and will bring the total cost of mitigation to an estimated $5,000. (This total includes a cost of $5 per drum and $1700 for conveyance of loaded drums to a storage site.)

Proposed Separation of Combined Storm Sewers

The drainage area around the Station Street pump station is presently served by combined storm sewers. As noted earlier, current plans call for separation of these lines and subsequent discharge of storm sewage. Two options are considered to minimize the potential impact of contaminated runoff on ultimate receiving waters.

The first alternative involves delaying the separation until local decontamination measures are completed. This would allow storm runoff from the Life Science site and the surrounding area to continue to be routed to the sewage treatment plant for an extended period. The result would be a negative impact from further release of sewage wastewater into surface streams during periods of high runoff from potentially two sources: (1) pump station overflow and (2) decrease detention time.

As explained in Chapter V the Station Street pump station receives the sewage from the area around the Life Science site. During rainy periods, it receives the surface runoff as well. At these times the combined sewage and runoff flow exceeds the pumping capacity of the station. During particularly heavy storms this excess capacity delivers a discharge of raw sewage/rainfall mixture into Poythress Run.

It is probable that this would occur several times as a result of the Kepone mitigation proposal to delay sewer line separation. It is difficult to quantify the magnitude and frequency of the impacts as they would be a function of the actual precipitation pattern during the months in which the delay takes place. However, even during an extremely wet period, the resulting adverse environmental impacts would not be measurable. No new stresses would be placed upon the environment since the overflow situation described is the present condition and one which has occurred for many years. Although it is desirable to eliminate this source of pollution, an additional delay of a few months would not have a detrimental environmental impact on Poythress Run.

A delay in separating the storm sewer line could also negatively impact the quality of the effluent discharged from the Hopewell primary sewage treatment plant (STP). When the runoff from the Station Street area reaches the treatment plant, the detention time for settling out the solids from raw sewage in the clarifiers is decreased due to the higher flow. As a result, the supernatant, which is then chlorinated and discharged, is of slightly poorer quality.

Delaying the sewer separation would allow this situation to exist for an additional period of time. The extended time would not create any additional significant adverse impacts to the receiving waters. This is particularly so considering that since August 1977 the primary sewage treatment plant has not discharged its effluent into Bailey Creek. The effluent is now being routed to a large regional treatment facility where it undergoes further settling and secondary treatment.

The second alternative for minimizing Kepone contamination resulting from sewage line separation involves treating the runoff collected before discharging it into the natural waterways. Although the details of the specific treatment facility are not available, it is assumed that it will be similar to a small-scale municipal water treatment plant. This would involve some filtering mechanism and an activated charcoal treatment process.

The treatment facility should not result in any liquid or gaseous effluents that could potentially impact the surrounding environment. However, the disposal of the Kepone-accumulating medium will require proper management to avoid adverse impacts. Burial of the spent activated charcoal in a lined pit would be considered adequate from an environmental standpoint and would demand a commitment of a small area of land.

A land commitment will also be associated with the site of the treatment facility itself. Although no more than a few acres at most would be involved, such a commitment could have a significant impact. This can occur in residential areas where the addition of even a small-scale, clean industrial-type activity is considered an intrusion into the character of the neighborhood. In siting a facility for treating the Kepone-contaminated runoff this fact must be considered. A majority of the drainage area around the Life Science site is a commercial/industrial zone, where, with proper planning, potentially conflicting land use problems can be avoided.

Based on these impact considerations, it is deemed advisable to delay separation of combined storm sewers until the contributing soil areas have been cleaned. This alternative involves no cost and no new environmental impacts. In essence, the "no action" alternative has some merits for this particular set of circumstances.

The Sewer System

Two options were considered for restoration of contaminated sewer lines: (1) caustic dissolution; and (2) mechanical or hydraulic cleaning. The first would require up to $5000 in chemicals and perhaps an equal amount in labor. It involves a technique which has not been demonstrated and which, if not conducted properly, could have acute impacts on the new sewage treatment plant and subsequent receiving waters. Mechanical cleaning is estimated to cost up to $47,000 if all trunk lines are addressed.

In both cases, costs are excessive for the estimated 0.11 kg (0.24 lb) of Kepone associated with the sewer slimes in trunk lines which could be cleaned. Conventional cleaning could not possibly address the collector system. Hence, subsequent flow will be able to recontaminate lines from Kepone in the smaller feeder lines and storm sewage from the Station Street area. The combination of these factors (uncertainty, high costs, incomplete removal, and small total inventory of Kepone which would be removed) is considered adequate justification for taking no major action on the sewer system.

The Sewage Treatment Plant

Some concern has been expressed that with operation of the new regional treatment plant, Kepone discharges from the old plant will contaminate sludge and in so doing raise the cost of disposal. It is currently estimated that under dry weather conditions old treatment plant effluent carries 6.5 g/day (0.014 lb/day) of Kepone. Under wet weather conditions, this increases to 37.6 g/day (0.0829 lb/day). The new regional plant will handle 87,670 kg (193,280 lb) of dry sludge per day and 50 million gallons of water. This corresponds to 0.07 μg/g (ppm) Kepone dry weather and 0.43 μg/g (ppm) Kepone wet weather concentrations in solids, if all Kepone is concentrated in the sludge. If all Kepone remains in the wastewater, the associated concentration would be 0.03 μg/ℓ (ppb) and 0.19 μg/ℓ (ppb), respectively. Grab samples taken on 1/12/78 were found to contain 0.057 μg/ℓ (ppb) Kepone in the influent and 0.072 μg/ℓ (ppb) Kepone in the effluent. The biological portion of the plant was not functioning well at that time, and therefore uptake on solids was likely to be less than that anticipated when the plant is operating properly. These levels are at the margin of detectability. The sludge will be incinerated in a multiple hearth facility operated at 1400°F with a solids residence time of 30 min. This facility will not destroy the Kepone because the temperature is too low for destruction. Instead hot exit gases will volatilize Kepone from the sludge and carry it from the chamber.

The Lagoon

As noted earlier, sampling to date strongly suggests that the disposal lagoon at the old sewage treatment plant is allowing additional Kepone to reach Bailey Creek. The alternatives available for sealing the lagoon will cost $10,000 to 24,000. Those alternatives utilizing a bottom seal or grout will stop inflows but will not prevent storm inflows and subsequent overflow. Consequently, a surface seal is advised. The 10-mil PVC sheeting will be least expensive and should maintain integrity until an ultimate disposal option is available.

Minimal adverse impacts can be attributed to covering the lagoon. During rainstorms there would be an increased amount of runoff from this area which would tend to increase erosion locally, particularly since the lagoon sits on top of a steep bank above Bailey Creek. However, this incremental increase of erosion is insignificant relative to the total amount of erosion in the nearby landfill area and to the suspended sediment load in Bailey Creek.

Man-made lagoons often support a variety of biota. This is the case with the Kepone lagoon based on observations made during the summer of 1977. Birds were often seen feeding among the rich vegetation growing in the sludge. Insects and algae were also abundant throughout the summer and for a few weeks a turtle made its home in the lagoon. Covering the lagoon to inhibit rainfall intrusion would eliminate the lagoon as a habitat. In light of the knowledge of Kepone uptake in the food chain and its toxicity, this habitat elimination would actually be a positive environmental impact.

Summary of Mitigation Activities

Based on the working criteria presented in this scenario, mitigation would be deemed advisable in five areas: Nitrogen Park, the former Life Science Products plant site, open lots in the Station Street neighborhood, the marsh below the bulk discharge area at the Hopewell landfill, and the Kepone disposal lagoon. The no action alternative appears justified for the contaminated sewer lines, the proposed separation of combined storm sewers in the Station Street area, and the Pebbled Ammonium Nitrate Site. A summary of costs associated with these actions can be found in Table IX.13. These costs do not include the cost of ultimate disposal for the highly contaminated soils and sediments (>1000 μg/g-ppm Kepone). Soils contaminated at less than 1000 μg/g (ppm) Kepone can be buried in clay lined pits at the landfill.

TABLE IX.13. THE COST OF PREFERRED MITIGATION ALTERNATIVES

Site	Alternative	Cost
Life Science Products Plant	Scraping - drum residuals	$ 1,050
Nitrogen Park	Cover and reseed	3,500
Station Street Neighborhood	Scrape and bury	2,200
Lagoon	10 mil PVC cover	15,000
Landfill	Excavate and drum	5,000
	Total	$26,750

DISPOSAL

While an evaluation of technology for the disposal of Kepone was not within the scope of the work reported here, it is obvious that in the long term, the alternatives evaluated for Hopewell require some means of ultimate disposal. Consequently, a survey of available technology was conducted.

Studies directed to this subject have also been performed by others and should be reviewed if a detailed evaluation is desired (Flood & Associates, 1977). The following is a brief summary of oxidation processes as a means of destroying Kepone contaminated residues.

Kepone Destruction

The recommended procedure for the disposal of organic pesticides is incineration at 1000°C (1832°F) for a 2-sec retention period. Other temperature and retention time combinations resulting in complete destruction of the material are permissible. The thermal properties of Kepone indicate that molecular destruction should occur under such conditions.

Research on the thermal degradation of Kepone revealed that the parent material is essentially destroyed in 1 sec at 500°C (Carnes, 1977). Thermal decomposition products exist at elevated temperatures and are subject to complete breakdown under favorable conditions. Figure IX.2 gives the thermal destruction pattern for Kepone. Hexachlorocyclopentadiene, K_a, hexachlorobenzene (HCB), K_c, and an unknown, K_b, are the major decomposition products in air.

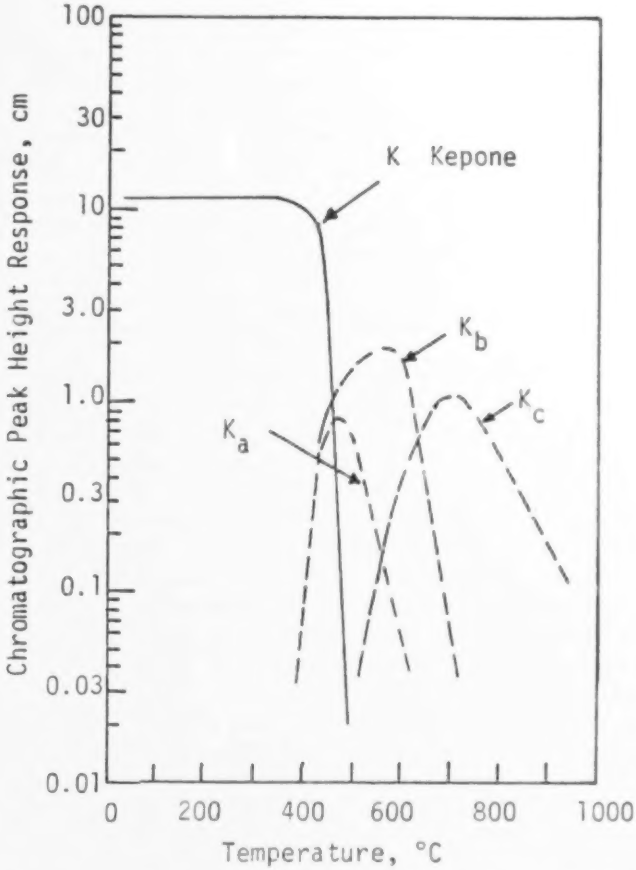

FIGURE IX.2. Thermal Destruction Plot for Kepone (Carnes, 1977)

Thermal properties of Kepone were determined through tests on the gas phase at varying exposure temperatures. Analytical grade Kepone was vaporized in the temperature range 200 to 300°C. The sample was then passed through a high temperature quartz tube. Degradation products were trapped after passage through the quartz for analysis by gas chromatography. Differences in thermal degradation, noticed at temperatures above and below 600°C, are primarily due to variations in the degradation products (Carnes, 1977).

Any thermal disposal method must ensure complete combustion of the degradation products as well as the parent compound. Hexachlorocyclopentadiene is a toxic material with a threshold limit value of 0.01 ppm or 0.11 mg/m^3 (Sax, 1975). During the thermal testing of Kepone, temperatures of 700°C effectively destroyed the hexachlorocyclopentadiene. Hexachlorobenzene produces toxic chlorine fumes when heated. Other potential combustion products are HCl and $COCl_2$ (Scurlock et al., 1975). Incineration is an acceptable disposal method, preferably after mixing with another combustible fuel to assure complete combustion. Trace amounts of HCB were still present at 900°C (Carnes, 1977).

Kepone has been found to be slightly more thermally stable than DDT. DDT was thermally tested in the same fashion as described above. In the p,p'-DDT form destruction of parent and decomposition products was complete at 900°C. Safe DDT incineration has been established as 1000°C for 2 sec or primary combustion at 815°C (1500°F) for 0.5 sec and secondary combustion at 1205°C (2200°F) for 1.0 sec (Powers, 1976). Any incineration requirements for Kepone should, at a minimum, meet those for DDT. Figures IX.3 and IX.4 give the destruction pattern for DDT and compare the thermal destruction of Kepone and DDT.

The Capabilities of Current Incineration Technology

As a general rule most organic hazardous materials can be completely destroyed at 1000°C with a dwell time of 2 sec. Actual wastes are generally mixtures or solutions and may be mixed with other materials. Incinerators vary in their application, combustion temperatures, residence times and economics. Only a few are suitable for Kepone destruction, partially because combustion of Kepone may produce chlorine. Halogens, such as chlorine, act as activity suppressants on catalysts thereby limiting their use. Chlorine is difficult to remove with secondary abatement methods. Sufficient hydrogen, in the form of natural gas or other combustible materials for reaction with chlorine to produce HCl, will allow wet scrubber removal. However, HCl corrosion must be considered in the incinerator design and equipment.

The following are descriptions of the different incinerator types and their suitability for Kepone disposal. The process principle, its range of application, combustion temperatures, and residence times for each is given. More detailed descriptions are given in Scurlock et al. (1975) and Powers (1976).

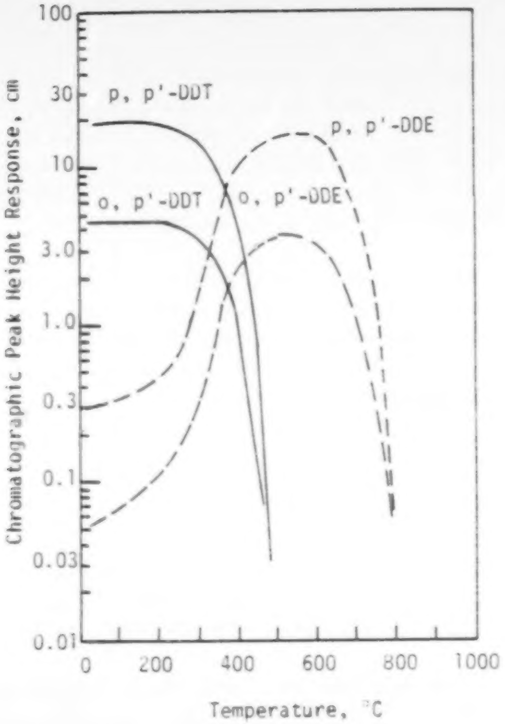

FIGURE IX.3. Thermal Destruction Plot for DDT (Carnes, 1977)

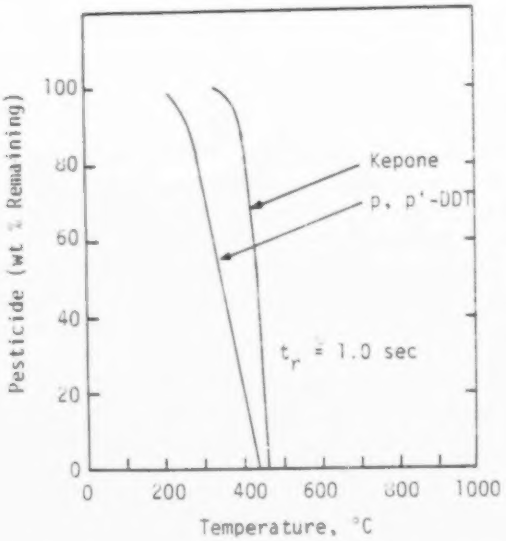

FIGURE IX.4. Comparison of Thermal Destruction of the Two Pesticides (Carnes, 1977)

Rotary Kiln

Combustion temperatures of 810 to 1650°C (1500 to 3000°F) are achieved in the slowly rotating cylinder mounted at a slight incline to horizontal. Residence times of several seconds to several hours accommodate the gases, liquids and solids that can be handled. Tumbling action improves the efficiency of solid waste disposal. Past applications include adaption for obsolete chemical warfare agents and munitions.

Rotary kiln incineration is adaptable for Kepone destruction. Auxiliary fuel can be added, and times and temperatures are capable of complete combustion. Most installations, particularly those handling hazardous wastes, are equipped with wet scrubber emission controls. Caustic scrubbing solution would be most effective.

Multiple Hearth

In a multiple hearth furnace, solids move slowly through vertically stacked hearths. Liquids and gases are fed through side ports and nozzles. Retention time may be up to several hours depending on the solid waste. Incineration temperatures are from 760 to 980°C (1400 to 1796°F). Emission control devices are usually integral to system design.

Pilot test burns on pesticides have been completed. Mixed with sewage sludge, the pesticides 2,4,5-T and DDT were incinerated at 870 to 930°C (1600 to 1700°F) with destruction ratios of 99.9%. Modification for Kepone destruction should be feasible, but would require entry at the fire box rather than from the normal feed port. Entry at the feed port will allow hot exit gases to volatilize Kepone and sweep it from the system prior to reaching the necessary temperatures for combustion.

Liquid Injection

Although combustion temperatures and retention times would meet requirements for 1000°C for 2 sec for incineration, the process is limited to pumpable liquids and slurries. Liquids with a viscosity of 10,000 SSU or less (reduced to 750 SSU or less for vaporization) are mixed with an atomizing gas for combustion at temperatures of 650 to 1650°C (1200 to 3000°F) at retention times of 0.1 to 1.0 sec in the vertical or horizontal reaction vessels.

Liquid combustion incinerators constructed specifically for chlorinated hydrocarbons have effectively handled pesticides. Incineration of Kepone would require auxiliary fuel, but Kepone in solution could be handled.

Fluidized Bed

Wastes are injected into a hot agitated bed of inert granular particles. Heat is transferred to the wastes, either solid, liquid or gas, from the bed material. Auxiliary fuel must be added to materials with low heating values. Solids are retained longer than gases which take several seconds to move through the bed material. Design limits the bed temperature to 1090°C (2000°F) while usual combustion temperatures range 750 to 870°C (1400 to 1600°F). Application to herbicide orange has been effective.

Temperatures limit use of fluidized beds for incineration of Kepone. Auxiliary fuel would be necessary. Removal of inert ash from the vessel is also a potential problem. The major concern is the degradation of hexachlorobenzene and its presence at 900°C after 1 sec. Chlorine containing wastes have been incinerated but no details were given to substantiate a recommendation.

Molten Salt

Combustion occurs in a bed of molten salt (usually sodium carbonate) where the salts may retain some of the decomposition products. Combustion temperatures of 900 to 950°C are maintained in the salt. Complete combustion of combustible gases occurs in a second reaction zone. Average retention times of 0.75 sec has proven acceptable for solid, liquid, and gaseous organic wastes.

Molten salt incineration has been modified for pesticide disposal in the past. Combined with an oxygen source, the pesticide is decomposed in the salt and second reaction zones. The evolved gases are essentially carbon dioxide, water vapor, oxygen and nitrogen (Powers, 1976). Contaminated containers can also be handled.

Several quantities of Kepone-contaminated waste were produced during the laboratory portions of the work reported in this document. Some of the aqueous wastes were concentrated on activated carbon and processed in a small laboratory molten salt incinerator for destruction. Analysis of emissions indicated over 99.6% destruction in one of two salt mixtures tested. Details of the work are presented in Appendix N.

Wet Oxidation - Zimmerman Process

Soluble and water miscible materials are oxidized under high pressure at moderate temperatures. Breakdown products, including halogens, are retained in the liquid effluent. Temperatures of 150 to 340°C (300 to 650°F) are used and pressures range from 316,000 to 1,758,000 kg/m^2 (450 to 2500 psig). Average residence times are 10 to 30 min.

Standard wet oxidation is not advisable for Kepone incineration. Specific studies would be required to ascertain the ability of the process to destroy Kepone and its decomposition products. Kepone is not readily soluble at pH values lower than 10 and high pH values are reported to decrease the process reaction rates, requiring compensating increases in temperature and pressure.

However, recent work at Allied has indicated that under proper conditions wet oxidation can be an effective means of destroying Kepone at less expense than incineration (Patterson, 1977). Kepone, Mirex and Kepone cleanup wastes were mixed with water to form solutions or slurries of up to 5%. These were charged with sufficient sodium hydroxide to provide a 0.5 molar solution at the completion of the reaction. The solution was then pressurized in the presence of oxygen for 2 to 10 min at 300 to 350°C. Pressures of 1.4 to 1.5 x 10^6 kg/m^2 (2000 to 2200 psi) were required to keep the water in a liquid state. The alkali aided dehalogenation and helped prevent the formation of a substantial carbon dioxide gas phase.

While experimental variables were not exhaustively explored, the conditions described were sufficient to reduce effluent Kepone concentrations to levels below the detection limit of electron capture gas chromatography. The rate of disappearance for both Kepone and Mirex was estimated at three orders of magnitude per minute. The enclosed nature of the process facility is considered a major advantage since it precludes releases resulting from incomplete reactions.

Discussions with technical staff at Zimpro indicate operational problems may result from wet oxidation of Kepone. Zimpro has conducted inhouse work on Kepone and they determined at that time that hydrogen chloride release posed a corrosion problem for steel systems and hence directed their attention to titanium. The use of titanium dictated acid conditions which were not effective for Kepone oxidation (30% reduction at 280°C). According to Mr. Robert Eely of Zimpro, caustic solutions are incompatible with titanium. Consequently, corrosion problems exist for both materials currently used in wet oxidation equipment. No economic alternatives have been identified to date. In general, if wet oxidation is employed it will cost in the range of 1.32¢/ℓ ($0.05/gal) for operation, maintenance and amortization. Basically, wet oxidation units have capital costs three times those for incineration but operating costs are one tenth.

Plasma Destruction

A gas, such as helium or air, is exposed to microwave energy and in the excited state forms a plasma. Degradation of organic bonds occurs from the transfer of energy as a result of collisions between reactant molecules and electrons in the plasma. Gases, liquids and solids have been processed in the 150°C (300°F), 5 to 150 torrs, and 3.7 to 4.7 kW oxygen plasma environment (Oberacker et al., 1977). Residence times range from 0.1 to 15 sec.

Using microwave plasma techniques, conversion of solid and liquid Kepone to CO_2, CO, HCl, and H_2O was 99% complete (Oberacker et al., 1977). Solids decomposed in 15 sec at 7 to 54 torrs in 42 to 4.6 kW plasmas. A commercial, clay-supported Kepone of 80% was used. Differences in pressure and oxygen flow will govern the retention time which can range from 10 to 30 sec for solids. Decomposition of Kepone at pilot plant scale is feasible.

Multiple Chamber

Wastes are combusted on a grate in an ignition chamber. Off-gases travel through mixing and secondary combustion chambers. The process is limited to solids and cannot handle liquids, slurries, and powders. Solids react in minutes, while gases react in seconds to the 540°C (1000°F). Municipal and industrial solid wastes are the common materials handled.

Multiple chamber incineration alone is not suitable for Kepone disposal. Suitability can be achieved, however, if appropriate afterburner devices are included in the design.

Gas Combustion

Flare, direct flame and catalytic oxidation are the three basic types of gas incinerators. Flares are not suited for hazardous materials as burning is performed in the open. Direct flame combusts gases with Btu values less than 25% of the lower flammable limit at elevated temperatures (450 to 810°C or 350 to 1500°F) for 0.3 to 0.5 sec. Materials are preheated prior to exposure to a catalyst bed where oxidation occurs. Gases are combusted in 1 sec at 320 to 540°C (600 to 1000°F).

Gas combustion is not suited for Kepone incineration. Conversion of solid Kepone to gas is unnecessary since other methods exist capable of solids destruction. Retention times and temperature for direct flame would require increases to assure total breakdown. Halogens are not compatible with catalysts because they foul the reaction sites, thereby eliminating use of catalytic oxidation.

Pyrolysis

Thermal decomposition in the absence of oxygen converts organics into solid, liquid, and gas constituents. Temperatures of 480 to 810°C for period of 12 to 16 min provide thermal decomposition.

There has been no unit testing of pyrolysis on hazardous wastes or pesticides. Tests verifying the ability of the process to decompose pesticides would be required before recommendations on applicability could be made.

Cement Kilns

Some work has been performed recently on the destruction of PCBs in cement kilns (Black, 1977). Results show promise of providing an alternate incineration method which would be much more widely available than current waste incinerators designed for this purpose. Normal operation of cement kilns is in the range of 1370 to 1450°C with a very long residence of about 10 sec, more than adequate for decomposition of most chlorinated hydrocarbons including Kepone. The alkaline substances in the raw material fed to these kilns act as efficient scrubbers for the HCl produced. No work has been performed directly with Kepone, and facilities may require modification to accommodate the variety of waste forms presently awaiting disposal.

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CHAPTER X - ALTERNATIVES FOR THE MITIGATION OF KEPONE IN THE JAMES RIVER

SUMMARY

Content

Chapter X evaluates alternatives for mitigating or eliminating the adverse impacts of Kepone in the James River. The work reported in this chapter focuses on the evaluation of alternatives other than large-scale dredging, and treatment and/or fixation processes complementary to dredging. Three types of alternatives are presented including those which could be: 1) used to fix dredge spoils for disposal; 2) employed to treat elutriate from spoils; and 3) applied in situ as substitutes to dredging. Individual options within each of these categories are discussed as well. Analysis of these options leads to a comparison of costs for alternative clean-up approaches for the James River.

Findings

- In laboratory studies, two stabilization agents (molten sulfur and an organic epoxy grout) offered up to 1 order of magnitude reduction in Kepone leachate levels.
- Silicate-based stabilization agents available at the time of testing were found to be ineffective in reducing Kepone leachate concentration.
- Application of activated carbon to contaminated sediments decreases the availability of Kepone to the surrounding aquatic system.
- In laboratory studies, coal did not significantly inhibit Kepone transfer from contaminated sediment to the overlying water.
- Retrievable sorbents are capable of removing Kepone from contaminated sediments.
- Polymer film laid over the sediments in Bailey Bay is an insufficient mitigative action since perforation necessary to allow venting of degradation gases will also allow the escape of Kepone.
- Activated carbon and UV-ozone treatment are each effective in removing Kepone from certain aqueous solutions.
- Application of the laboratory tested options to the contaminated portions of the James River would cost in excess of $3 billion.

- Unit Costs for mitigation alternatives in the James River were estimated to be:
  - Application of Retrievable Carbon - \$0.52/ft^3 sediment
  - Application of Retrievable Sorbent in Situ - \$0.90/ft^3 sediment
  - Oozer Dredge with Ocean Disposal - \$1.07/ft^3 sediment
  - Oozer Dredge with Sulfur Stabilization - \$1.37/ft^3 sediment
  - Oozer Dredge with Incineration - 1.57/ft^3 sediment

INTRODUCTION

Currently, dredging constitutes the most developed and best understood means for removal of contaminated sediments. A review of worldwide dredging technology and/or engineering analysis of application of dredging to the James River problem is given in a companion report by the U.S. Corps of Engineers, Norfolk District - "Capturing, Stabilizing, or Removing Kepone in Bailey Bay, Bailey Creek and Gravelly Run," as a part of the overall U.S. Environmental Protection Agency Mitigation Feasibility project. Coverage in that work includes advanced Japanese technology in dredging and fixation of contaminated sediments.

This chapter evaluates the existence of alternatives to dredging as well as the consequences of taking no corrective action in the river, thus allowing natural dilution and dispersive mechanisms to cleanse the river over time. For the purposes of evaluating scope and costs of applying individual alternatives, it was necessary to determine the extent of the contamination and the size of the areas to be treated. From historical data and the field investigations reported in this report, it has been shown that over 113 Km (70 linear miles) of the James River have sediments with detectable levels of Kepone covering about 630 km^2 (243.1 mi^2). The fractional distribution of concentration regimes has been defined as follows:

Concentration of Kepone (µg/g-ppm)	>10	1-10	0.1-0.99	0.02-0.09
Approximate Percentage of Total Area	0.1%	1.0%	45.18%	53.7%
Approximate Percentage of Total Kepone (1 ft depth) Kepone has been detected as low as 1 meter, but 1 foot is employed as an average for costing purposes	3%	16%	73%	8%
Area in Square Miles	0.243	2.43	109.8	130.5

Similarly, contamination by river reach has been identified as:

	Richmond to Jordan Point	Jordan Point to Jamestown Island	Jamestown Island to Newport News	Hampton Road	Total
Area (mi^2)	4.6	44.9	132.7	60.9	243.1
Percent of Total Area (%)	2	18	55	25	100
Kepone (lb) (1 ft depth)	5,033	13,160	21,000	2,400	41,593
Percent of Total Kepone (%)	12	32	50	6	100

DREDGE SPOIL FIXATION

While dredging is a recognized approach to the removal of in-place toxics, it was not the purpose of this study to compare available dredging technology. Such a comparison is offered in a companion report to this document, "Capturing, Stabilizing, and Removing Kepone in Bailey Bay, Bailey Creek and Gravelly Run at Hopewell, Virginia," by the Norfolk District Corps of Engineers. This work addresses the disposal of resultant spoils.

It has long been known that the disposal of toxic liquids or sludges onto land disposal sites can lead to ground-water and airborne contamination due to leaching and resuspension by wind. Consequently, various materials have been identified as stabilization or fixation agents capable of solidifying these wastes and minimizing subsequent movement of contaminants. Candidate materials include asphalt, tar polyolefins, epoxy resins, silicates, and elemental sulfur. The desirability of any one fixation agent is based on the characteristics of the contaminant to be bound as well as stresses to which the fixed mass may be exposed (e.g. pressure, thermal changes, etc.).

In the past, fixation processes have largely been applied to wastes containing inorganic contaminants such as heavy metals (Anonymous, 1975). In this context, the silicates have been relatively successful. Cadmium from electroplating sludge leached at much slower rates when fixed than it did from raw sludges. Success has also been reported using a polybutadiene binder resin and a polyethylene encapsulating agent on toxicants such as copper, chromium, zinc, nickel, cadmium, mercury and monosodium methanearsenate (Wiles and Lubowitz, 1976). However, little has been done to measure the effectiveness of these agents to retard the leaching of persistent organic contaminants. Therefore, it was necessary to conduct a series of laboratory studies to evaluate the effectiveness of fixation agents on reducing leachate Kepone concentrations from contaminated sediments.

Procedures

Each fixation agent evaluated was subjected to two types of standardized tests: (1) a short-term elutriate test and (2) a longer term leach test. The results of these were employed to assess the overall effectiveness of a particular set of fixation agents. High levels resulting from the elutriate assessment reflects potential to cause immediate impact. Contamination of leachate carries long-term implications. All fixation work was performed on a "standard" sediment prepared through homogenization of a large sample of Bailey Bay sediments. The Kepone concentration in these samples has been measured at 1.17 ± 0.13 ℓμg/g (ppm).

The standard elutriate test employed for these studies was modeled after a procedure described by Keeley and Engler (1974) from work at the U.S. Army Corps of Engineers Waterways Experiment Station. Specific changes include an increase in the sediment to water volumetric ratio from 1:4 to 1:19 as recommended by Lee et al. (1975). This reduction to a 5%

slurry is made to accommodate lower total contaminant levels in the elutriate as a result of reduced solubilities characteristic of chlorinated hydrocarbons. The elutriate pH was also modified. Based on work by Esmen and Fergus (1976), distilled water with an adjusted pH of 4.5 was employed to simulate rainfall. Adjustment was accomplished with HCl, and hence, buffering action was not increased.

Based on these modifications, elutriate tests were conducted as follows:

1. All samples were held at 4°C prior to testing.
2. Fixed sediments were ground to pass through a 10 mesh screen.
3. Distilled water at pH 4.5 was added to the ground sediment at 19 parts water to 1 part sediment (5 %).
4. The slurry was mixed vigorously for 30 min on a horizontal displacement mechanical mixer.
5. Mixtures were allowed to settle for 1 hr.
6. Settled slurries were centrifuged at 3500 rpm for 30 min and centrate filtered through a 0.7-2 μ Gelman glass fiber filter.
7. Finally, the filtrate was analyzed for Kepone and compared to results obtained with unfixed sediments.

Similar considerations were made in designing the leach test employed. Specific steps included:

1. All samples were held at 4°C prior to testing.
2. Blocks of fixed sediments were weighed and reduced in size to the diameter of pea gravel or less.
3. Approximately 70 g (0.154 lb) of particles were placed in sealed leaching bottles and 500 ml (0.132 gal) of distilled water at pH 4.5 were added.
4. At each sampling time interval the water was removed from the vessel and a new pH 4.5 500 ml (0.132 gal) aliquot was added.
5. Removed aliquots were split. Half were sent for Kepone analysis, and half were collected as a composite to assess total Kepone losses.
6. Sample intervals were selected as 1, 4, and 24 hours; 7, 14, 28, and 84 days.

Results

Only commercially available fixation agents were employed for the studies reported here. To identify candidates and avoid arbitrary exclusion of any options, an attempt was made to contact all companies currently marketing fixation processes. Firms identified for this purpose and their subsequent response are detailed in Table X.1. All companies were offered the opportunity to participate, but not all chose to do so. "Standard" sediments were employed for all fixation trials as well as for blanks.

Data were obtained on all samples for both elutriate and leach tests. These are presented in Table X.2. Many of the agents employed are proprietary in nature and therefore not identified here. The first samples are from fixation tests performed by Ontario Liquid Waste Disposal Ltd. Their process

TABLE X.1. CANDIDATE FOR FIXATION AGENT TESTING ON KEPONE CONTAMINATED SEDIMENTS

Company	Address	Response
Chemfix-National Environmental Controls, Inc.	Metairie, LA	Fixed samples at company
TJK Ind.-U.S. Representatives for Takenaka	7407 Fulton Ave. North Hollywood, CA 91605	Fixed samples at company and sent chemicals for in-house fixation
IU Conversion System	Plymouth Meeting, PA	No response
Protective Packaging	Louisville, KY	Not developed enough for testing on sediments
John Sexton Landfill Contractors	Oakbrook, IL	No response
Werner and Pfluidores, Corp.	Waldwick, NJ	No response
Wehran Engineering Corporation	Middletown, NY	No response
Ontario Liquid Waste Disposal Systems	470 Collier MacMillan Dr. P.O. Box 1060 Cambridge, Ontario	Fixed samples at company
TRW Inc.	Redondo Beach, CA	Not developed enough for testing on sediments
Manchek Colorado	P.O. Box 30737 Santa Barbara, CA	Fixed samples at company
Key Chemicals	4346 Tacony St. Philadelphia, PA	Sent samples of sediment, fixed at company
Dowell Division, Dow Chemical	Tulsa, OK	Sent chemicals for fixation and testing
Hallemite Division, Sterling Drug Co.	225 Summit Ave Montvale, NJ 07645	Sent chemicals for fixation and testing
Randustrial Corp.	13311 Union Ave Cleveland, OH	Sent chemicals for fixation and testing
Tidewater Terminal Co.	Pasco, WA	Sent asphalt sample for fixation and testing
Surcoat	Chevron San Francisco, CA	No response

TABLE X.2. KEPONE CONCENTRATIONS IN ELUTRIATE AND LEACHATE SOLUTIONS (μg/ℓ-ppb)

Fixation Type	Elutriate	Time in Hours								Composite of Leachate
		1	4	24	168	336	672	1344	2016	
Silicate Base										
Ontario Liquid Disposal No. 2		0.07	0.08	0.094	0.166	0.524	0.30		0.26	0.17
Ontario Liquid Disposal No. 3		0.05	0.05	0.111	0.157	0.306	0.26		0.51	0.26
Ontario Liquid Disposal-Pickle Liquor		4.10	4.04	3.55	1.75	3.56	1.39	1.59	1.24	2.90
Manchek Colorado No. 2	3.52	1.04	0.99	1.01	1.81	1.74	2.09		3.9	1.90
Manchek Colorado No. 3	1.27	1.34	2.64	0.90	1.30	1.18	0.78		1.76	1.40
Manchek Colorado No. 4	1.91	1.33	1.88	1.31	1.42	1.04	1.02		3.86	2.20
Manchek Colorado No. 5	1.31	0.39	0.54	1.00	1.18	1.27	1.41		2.59	1.49
Chemfix CT-77-2A	0.12	1.90	3.30	2.27	2.93	3.58	3.58	43.9	3.77	1.95
Chemfix I-4	0.012	1.52	2.44	1.62	1.64	2.10	1.42	1.96	2.42	1.50
TJK, Inc. 101	0.078	0.095	0.068	0.059	0.15		<0.21	0.31	0.77	0.77
TJK, Inc. 102	0.055	0.088	0.083	0.088	0.14		0.11	0.49	2.84	0.45
TJK, Inc. 201	0.069	0.21	0.24	0.21	0.16		0.096	0.14	0.81	0.83
TJK, Inc. 301	0.037	0.35	0.13	0.073	0.065		0.073	0.18	3.30	2.01
TJK, Inc. 302	0.055	0.12	0.18	0.14	0.079		0.096	1.89	0.33	0.44
Tunnel Holdings 4A	1.29	0.35	0.45	54.8	0.41		0.53	1.32	2.24	0.96
Tunnel Holdings 4B	0.24	0.046	0.088	0.068	0.67		0.033	0.11	0.15	0.24
Organic Base										
Por Rok Epoxy Grout	<0.037	0.042	0.075	0.021		<0.055	0.034	0.057	0.021	<0.049
Dowell M179	29.3	0.086	0.044	0.018	0.053	0.095	0.21	0.28	0.083	0.074
Sulfur Base										
Molten Sulfur		0.013	0.012	0.017	0.010	0.05	0.029	0.032	0.15	0.17
Sulfaset	0.14	0.5	0.22	0.095	0.20		0.28	0.31	0.29	0.45
Gypsum Base										
Por Rok	Decomposed	0.52	0.47	0.52	0.91	0.92	0.80	1.01	0.74	0.99
Blank No. 1	0.042	<0.066	<0.066	0.076	0.058	0.050	0.22		1.04	0.10
Blank No. 2		0.117	0.04	0.104	0.081	0.11	2.30		0.14	0.26

involved the addition of an acidic agent followed by an amending agent with dosing controlled through observation of pH levels. Sample 3 included the addition of soil to assist the binding process. Sample 4 employed pickle liquors for the acid component. All samples showed Kepone concentrations in leachate in excess of those for untreated sediment. The soil amendment enhanced fixation slightly for short exposure periods but did not have a positive effect on Kepone levels in the cumulative leachate.

The second set of samples was prepared by Manchek-Colorado, Inc. They employ an oxidizing agent, a fixative agent, and an amendment using temperature changes for process control. Sample 2 did not include the amendment. Sample 3 included the amendment and was prepared at 130°F. Samples 4 and 5 were also prepared at 130°F but received increasing amounts of amendment. Leachate from these four samples generally contained ten times the concentration of Kepone than did leachate from the untreated sediment.

Two mixtures of the Chem Technics patented fixative called Chemfix were evaluated. These samples, labeled I-4 and CT-77-2A, never had a leachate within an order of magnitude of the blank leachate. It is assumed that because of the high pH occurring during the mixing and curing steps of fixation, Kepone was dissolved and released from the sediment. During the leach tests the free Kepone readily migrated to the leachate water.

Five samples were obtained from TJK, Inc. Each is a variation of a basic silicate based fixation agent developed by Takenaka of Japan. Three of the formulations displayed higher leachate concentrations than standard sediments much as the other silicate based fixation agents. Two of the formulations produced leachate Kepone levels roughly equivalent or slightly lower than those from standard sediments for specific sampling times, but all cumulative leachate levels exceeded Kepone concentrations for the unfixed sediments. Additional samples have been provided TJK for in-house development.

Two samples of silicate based agents were obtained from Tunnel Holdings Ltd, Inc. of the United Kingdom. Both displayed leachate Kepone levels in excess of those produced by the sediments alone.

In general, the silicate based agents rely on high pH conditions to set the stabilized material. Kepone is solubilized under these conditions and therefore is present in leachate at equivalent or higher levels than is found with natural sediments. There is also some adverse action from the low pH (4.5) simulated rainwater on the fixation agent itself.

Por Rok and Por Rok Epoxy Sealant are both grout materials manufactured by Hallemite, Inc. Por Rok is a gypsum base material and consequently will not retain much structural integrity when immersed in water. When comparing the leach results with those of the natural sediment there was generally ten times the Kepone leached from the fixed sediment than from the blank. The Por Rok Epoxy Sealant is a synthetic epoxy material which is mixed with a coarse aggregate material and used as a grout or surface sealant. It produces leachate with Kepone concentrations, an order of magnitude lower than those of standard sediments. This stabilization agent shows promise as a means of reducing Kepone releases from spoils.

Dowell M179 is a soil sealant material. It is primarily comprised of a polyacrylamide polymer which resists water percolation. Its action is dependent upon formation of a film-like coating. The crushing employed in the elutriate test therefore compromised the integrity of the agent. The test was performed, however, to maintain uniformity in testing procedures. The poor response to the elutriate test reflects the breaking of the surface film and subsequent leaching from exposed surfaces. Short term leaching on the other hand (1 to 4 hr) yielded Kepone levels similar to those from untreated sediments. After 24 hr of exposure the M179 leachate had a concentration of 0.018 $\mu g/\ell$ (ppb), or approximately 1/10 of the concentration found in the blank. Subsequent leachate samples revealed a similar pattern. Consequently, the Dowell agent is considered well suited for its intended use as a surface seal and percolation control agent. Extended use for spoils stabilization is not recommended in that long-term immersion and physical stress could lead to puncture of the film and release as reflected by the elutriate data.

Two sulfur-based approaches were evaluated. The "sulfur sludge" combination involves the inclusion of spoils with molten elemental sulfur. This is a technology that has been evaluated for use on radioactive wastes and is employed for patching pavements. Sulfur is shipped commercially as a molten material. For stabilization the two are rapidly mixed upon contact and allowed to set. The Sulfaset is a proprietary agent distributed by Randustrial, Inc. and appears to include both sulfur and cement in the formulation. As is evident from Table X.2, the molten sulfur approach offered 1 order of magnitude reduction while the Sulfaset was less effective. The Sulfaset produced leachate intermediate between pure silicate based agents and molten sulfur. It produced high pH in leachates which are capable of solubilizing Kepone as was the case with the silicate agents. The composite Kepone concentration for the molten sulfur appears to be an anomaly since it is higher than any contributing leachate sample for a specific test period. Comparison of leachate levels at each test interval reveals a ten-fold reduction of Kepone constructions with molten sulfur.

Of the 21 proprietary and generic agents tested, two were found to show good potential for use on Kepone contaminated dredge spoils: Por Rok Epoxy Grout, and molten sulfur. The costs for use of these fixation agents have been calculated based on the following considerations:

Application Rate -	Molten sulfur-equal volume sulfur to dry sediment Epoxy Grout 14.5 gal/ton of sediment
Unit Costs -	Molten sulfur \$38-42/ton Epoxy Grout \$1.58/lb, \$14.41/gal Application Labor, etc. \$0.10/yd^3 Dredging \$2.95/yd^3, \$2.21/ton (oozer dredge)

This yields a composite cost for stabilization of \$45.90/m^3 (\$1.30/ft^3) for molten sulfur and \$442.30/m^3 (\$12.53/ft^3) for Epoxy Grout. Based on these costs, the cost of implementation for various segments of the river have been calculated in Tables X.3 and X.4. It should be noted that additional pilot and field studies are needed before extensive application of any fixation agent to Kepone contaminanted sediments.

TABLE X.3. COMPARATIVE COST OF IMPLEMENTING DREDGE AND STABILIZATION OPTIONS IN VARIOUS KEPONE CONCENTRATION REGIMES ON THE JAMES RIVER

River Segment by Kepone Concentration (µg/g-ppm)	>10	1-10	0.1-1.0	0.02-0.1
Dredge Volume (1 ft deep) (ft^3)	6.8×10^6	6.8×10^7	3.0×10^9	3.6×10^9
Dredge Cost (\$)	8.1×10^5	8.1×10^6	3.7×10^8	4.8×10^8
Molten Sulfur Cost (\$)	8.9×10^6	8.9×10^7	3.8×10^9	4.7×10^9
Epoxy Grout Cost (\$)	8.5×10^7	8.5×10^8	3.5×10^{10}	4.5×10^{10}

TABLE X.4. COST OF IMPLEMENTING DREDGE AND STABILIZATION OPTIONS IN VARIOUS REACHES OF THE JAMES RIVER

River Segment by Flow Stretch	Richmond to Jordan Point	Jordan Point to Jamestown Island	Jamestown Island to Newsport News	Hampton Roads	Total
Dredge Volume-1 ft depth (ft^3)	1.3×10^8	1.3×10^9	3.7×10^9	1.7×10^9	6.8×10^9
Dredge Cost ($)*	1.4×10^7	1.5×10^8	4.1×10^8	1.8×10^8	7.4×10^8
Molten Sulfur Cost ($)	1.7×10^8	1.7×10^9	4.8×10^9	2.2×10^9	8.9×10^9
Epoxy Grout Cost ($)	1.6×10^9	1.7×10^{10}	4.6×10^9	2.1×10^{10}	4.4×10^{10}

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*These figures do not compare directly with dredging costs developed by the Corps of Engineers, Norfolk District, as a part of the EPA Kepone Mitigation Feasibility Project since their cost evaluation included overboard disposal and a dredging depth of 15 in.

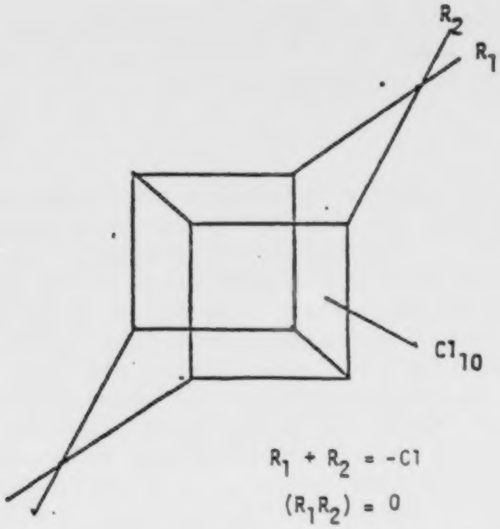
BIOLOGICAL TREATMENT

Microorganisms play an important role in the fate of many organic compounds in the environment. Bacteria (Guenzi and Beard, 1967; Hill and McCarty, 1967; Johnsen, 1976; Bollag et al., 1968; Tiedje, 1969; Duxbury, 1970) fungi (Kallman) and Andrews, 1963; Focht, 1972) and algae (Canton et al., 1977) have all been implicated in these interactions. Basically, positive microbial action can be divided into three categories: (1) degradation/utilization; (2) degradation/co-metabolism; and (3) bioconcentration. Utilization can be either aerobic or anaerobic. Co-metabolism is the degradation of a substrate from which no growth of the organism occurs. The process of bioconcentration can be either active or passive.

If there is a positive Kepone-microorganism interaction, it most likely involves one of the above processes. Furthermore, it is possible that these processes could be exploited to facilitate the collection and/or removal of Kepone from the James River.

There is much information in the literature concerning Kepone. However, little is devoted to the delineation of microbial interactions. To obtain more information for the purposes of evaluation, available data on microbial interactions with analogous chemicals and systems were also reviewed.

Mirex, and Kelevan, like Kepone, are prepared from hexachlorocyclopentadiene (HcP) (Figure X.1). Kepone and Mirex should be similar in their physical and chemical characteristics (Table X.5). Kepone is much more soluble in water than Mirex and the solubility shows a marked pH dependence (higher solubility with increased alkalinity). This factor alone may have profound significance due to local pH of the water or to the pH of the microenvironment since most microorganisms tend to alter the pH of their immediate environment.



$R_1 + R_2 = -Cl$ Mirex

$(R_1R_2) = 0$ Kepone

Kelevan $\begin{cases} R_2 = -OH \\ R_1 = -CH_2COCH_2CH_2CO_2CH_2CH_3 \end{cases}$

FIGURE X.1. Structures of Mirex, Kepone and Kelevan

TABLE X.5. SOLUBILITIES OF MIREX, KEPONE AND KELEVAN (ALLEY, 1973; SMITH, 1976; MAIER-BODE, 1976)

Solvent	Conditions	Solubility Mirex	 Kepone	 Kelevan
H_2O	25°C	1 ppb*		
NaCl	0.5%, 25°C	0.25 ppb		
H_2O	23.5°C		6.8 ppm** (Maier-Bailey, 1976)	
H_2O	pH 4-6		1.5-2 ppm (Smith, 1976)	
H_2O	pH 9-10		5-70 ppm (Smith, 1976)	
NaOH	0.001 M		176 ppm	
H_2O	20°C			5.5 ppm (Kelevan)
H_2O	20°C			67.0 ppm (Kelevan acid)

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*ppb = parts per billion (μg/ℓ)

**ppm = parts per million (mg/ℓ)

An organism tolerant of Kepone under acidic conditions may become adversely affected if the pH becomes alkaline. Conversely, a drop in pH might render the Kepone inaccessible to the organism.

Microbial Interactions

Brown et al. (1975) was unable to isolate any organisms which would grow solely on Mirex. An organism was obtained which would grow in the presence of hexane and Mirex but not on the individual compounds themselves. Brown et al. (1975) also reported that no degradation of Mirex was observed. It was their opinion that essentially all of the Mirex in aqueous solution would be removed by adsorption on particulate matter (clay and dead bacterial cells) and would resist degradation. They also state that there was no bioconcentration of Mirex. Analysis of their data shows that live cells accumulated as much as dead cells. A fine distinction can be made in that there is bioconcentration but that it is passive. No attempt was made to determine if the adsorption on clay and cells was preferential. In addition these authors omitted a large sector of the microbial population in their studies. Anaerobic bacteria, fungi, actinomycetes, and algae were not examined. All bioconcentration experiments with Mirex were performed using a single strain of *Beneckea* rather than a representative group of microorganisms.

Brown et al. (1975) shows that while 1000 mg/ℓ (ppm) Mirex was not inhibitory to the mixed microbial populations tested, 1 to 10 mg/ℓ (ppm) Kepone inhibited primary productivity and the growth of *Beneckea*, a marine bacterium.

The research of Jones and Hodges (1974) supports the findings of Brown et al. (1975) that mirex is resistant to microbial degradation. Vind (1976) was unable to show any degradation of Kepone in sea water incubated aerobically and anaerobically over a 12-month period. This correlates closely with results of shorter term experiments conducted by Gulf Breeze (Garnas et al. 1977) and Battelle (see Chapter IV).

Kelevan, which is synthesized by reacting ethyl levulinate with Kepone, is an interesting exception to the resistance to degradation seen with Kepone and Mirex (Gilbert et al, 1966). In soil the half life of Kelevan is between 6 and 12 weeks, depending on the soil. One of the intermediates of Kelevan degradation is Kepone (actually thought to be "Kepone-L-argine"). The loss of Kelevan is so rapid in the soil that residues are measured as Kepone. Before further examining the feasibility of Kepone amelioration by microorganisms, some insights gained during research on pesticides and related toxic compounds should be considered. Ahmed and Focht (1972, 1973) have reported that bacteria are incapable of degrading the higher chlorinated PCBs when no unsubstituted vicinal carbons are present. If this is in fact the case, a compound such as Kepone must undergo some degree of dehalogenation before oxidation can begin.

Dehalogenation has been shown to occur to a greater extent in anaerobic systems than aerobic systems (Andrade and Wheeler, 1974; Hicks and Corner, 1973). This is of particular interest since the heavily Kepone-contaminated areas of Bailey Creek and Bay are anaerobic. The deeper sediments in the James River carrying Kepone are also anaerobic and hence conducive to this type of chemical attack.

As yet, there is no evidence of the dehalogenation of Kepone in the environment. Consequently, subsequent bacterial degradation of the compound itself is not likely. Mono and dihydro derivatives have been identified in environmental samples, but this does not necessarily indicate dehalogenation. The latter may have been by-products released along with batches of Kepone and hexachlorocyclopentadiene. Studies sponsored by the Commonwealth of Virginia have revealed apparent Kepone degradation in sludge digesters (Design, Partnership, 1976). This suggests that all possibilities of degradation in the environment cannot be ruled out.

Role of Fungi and Mold in Biodegradation

The fungi have long been known for their metabolic diversity. They are also known to survive in harsh environments. Fungi, therefore, have been used by researchers to study the biodegradation of many recalcitrant organic compounds. Researchers at the Atlantic Research Corporation, Alexandria, Virginia maintain a collection of fungi and molds capable of degrading recalcitrant compounds. According to Ralph Valentine of that organization over 40 fungal and mold isolates were tested for their ability to grow on solid base media using Kepone as a sole carbon source. The identity of these media was not disclosed. Five cultures showed growth. One isolate showed a 41% disappearance of Kepone in 22 to 31 days. Disappearance was tested by gas-liquid chromatography using the method of the Commonwealth of Virginia for the analysis of Kepone in shellfish.

Although these results appear interesting, the data obtained by the Atlantic Research Corporation is preliminary and data do not give any indication of the applicability of fungi to the problem of in situ degradation. These are laboratory tests only and have not been applied in the field. Since the majority of Kepone in the Bailey Bay sediments is in a highly anaerobic environment, it is unlikely that the five aerobic fungal isolates of the Atlantic Research Corporation, would be capable of growth or Kepone degradation in that environment. Their use in the aerobic portions of the James River is a possibility, but competition from natural bacteria could be a limiting factor. Atlantic Research has stated that in situ applications appear unlikely at this time.

Co-metabolism (Co-oxidation)

As noted previously, no comprehensive information is readily available on the microbial degradation of Kepone. Data on Mirex degradation is scant and contradictory (Brown et al., 1975; Jones and Hodges, 1974; Andrade et al., 1975; Andrade and Wheeler, 1974). However, based on past information concerning the multitude of organic compounds degraded by microorganisms, the degradation of Kepone is a possibility. There is still a question of whether or not degradation is an actuality in the Bailey Bay environment. In concert with biological effects there are many possible chemical effects. The slow effect of photochemical decomposition cannot be ignored (Alley et al., 1973; Ivie et al., 1974), although the turbidity of the water and depth of Kepone contamination will minimize any possible effects. Surface catalyzed reactions carried out on the surface of organic or inorganic particles are also factors which must be considered. Finally, the contribution from indirect biodegradation (co-metabolism) must be analyzed.

In ecosystems that have had long standing or continuous inputs from industrial and agricultural (pesticides) sources, the probabilities for degradation or co-metabolism are enhanced. In addition, fungi and algae, which normally synthesize organohalides may be a good possibility for carrying out cometabolism (Chapman, 1976).

Bioaccumulation

Microorganisms

Bioaccumulation, whether active or passive, may be a method for concentrating Kepone for harvest and thus simplifying disposal. Active accumulation of pesticides is most often seen where the pesticide is metabolized or when it is an analog of a chemical which is normally transported. In active accumulation the process is energy-mediated such that the compound once inside the cell will be maintained inside and will not escape by simple diffusion. Passive accumulation is dependent on the chemical nature of the microbial capsule, wall, or membrane and is an adsorption phenomenon.

Bioaccumulation becomes an attractive option when it is easier to remove the accumulating biota than to remove the Kepone from the system. Algae would be the most simple to remove. Growing in mats, the algae could be skimmed off the surface. Bacteria and fungi would probably work best as immobilized cells in a filtering system. Some bacteria and fungi form flocs and extensive mycelial networks, respectively, which could be harvested in a manner similar to that of algae. Numerous examples exist which demonstrate the microbial accumulation of pesticides (Canton et al., 1977; Hicks and corner, 1973; Chacko and Lockwood, 1967; Johnson and Kennedy, 1973; Leshniowsky et al., 1970). Used alone or in conjunction with microbial Kepone degrading systems, bioaccumulation could be an attractive option. It is apparent from the literature that the process of bioaccumulation occurs in hours rather than the months needed for degradation. Bioaccumulation is not limited to the microbiota. Bahner et al. (1977) have reported bioconcentration of Kepone in mysids, grass shrimp, oysters, sheepshead minnows and spot. If treatment of the Kepone is to be handled in situ, then the use of an easily harvested bioaccumulation system may be necessary to reduce accumulation in higher life forms or biomagnification through the food chain. Bioaccumulation could also be used in the treating of Kepone spoils in order to concentrate and isolate the Kepone.

Plants

Plants may also bioconcentrate chlorinated hydrocarbons and other contaminants either through uptake from water or soils. As noted earlier, Newbauer tests with barley revealed no apparent uptake of Kepone from soil. Similar results are reported for PCBs. Mr. Paul Griffen of General Electric Company in his research on bioconcentration of PCBs has been unable to demonstrate the uptake of PCB from contaminated sediments by the water hyacinth (Griffen, 1977).

The research of Suzuki et al. (1977) supports to some extent the results obtained by General Electric in PCB studies. The Suzuki group observed PCB accumulation on roots of soybean sprouts. The lower chlorinated PCB isomers are preferentially accumulated by the soybean roots. This process is directly related to the water solubility of the PCB isomers. The more water soluble an organic compound the easier for plants to take it up and accumulate it. The lipophilic nature of many organic compounds enhances the transport of these compounds across biological membranes but decreases the possibilities of uptake by root systems. Hence, the less soluble (higher chlorinated) compounds are not readily taken up by the roots.

The maximum solubility of PCB in neutral waters is approximately 1 mg/ℓ (ppm) and that of Kepone is 5 to 6 mg/ℓ (ppm). However, the highest concentration of Kepone found during the June sample period was 0.042 mg/ℓ (ppb) and the majority of concentrations seen were less than 0.006 μg/ℓ (ppb). In sediment, the concentration of Kepone is considerably higher: in the parts per million range. This situation is analogous to that seen with PCBs and reflects the strong affinity of sediments for the contaminant which produces a partitioning heavily skewed to the sediment phase. This is discussed in detail in Part IV - Physical Chemical Properties of Kepone - under sorption-desorption.

For these reasons, the use of water hyacinths or other aquatic plants to remove Kepone from the contaminated sediments does not appear to be feasible. The plants cannot take up significant amounts of Kepone directly from the sediments where most of the contamination resides (see Chapter IV). They may sorb Kepone from water, but this will represent only a small portion of the Kepone available. Even though the Kepone in water can be removed, the water will remain contaminated as long as the sediment is contaminated. This results from desorption of Kepone from sediments to maintain a constant ratio (partition coefficient) between the sorbed and dissolved states.

IMPLICATIONS

In Situ Amelioration

The use of any biological alternative to treat the contaminated water of Bailey Bay would be practical only if the sediment is also undergoing treatment. The Kepone concentration in the water is significantly less than that in the sediment. Any method directed solely at treating the water will only serve to allow more Kepone to go into the solution from the sediments. Furthermore, since the Kepone concentration in water is so low it may be below the effective concentration needed to warrant the use of a biological method.

Benthic organisms that routinely ingest particles or filter feed accumulate Kepone (Collins et al., 1973; Bookout and Costlow, 1975; Bookout and Costlow, 1976). Any disruption of the contaminated sediments or reduction in the partition coefficient would serve only to enhance the dispersion of Kepone and create new areas of contamination.

Therefore, any biological alternative that reduces or inactivates the Kepone in intact sediments should receive a high priority. However, the majority of the biologic options discussed in this report are inoperative in these sediments.* Fungi responsible for degrading other recalcitrant compounds do so aerobically and cannot compete with natural bacterial populations. Algae would not be amenable to use under reducing conditions or in the absence of light in the sediment of areas such as Bailey Bay. The most promising alternative would be the use of the anaerobic bacteria if strains could be identified which could degrade Kepone biochemically. If in situ anaerobic bacterial degradation were successful, it would reduce the Kepone concentration in the water as well as in the sediments. Hence reduction in sediment levels would lead to further adsorption from water until a new equilibrium was established. As noted in Table X.6, no biological approaches have been identified with the potential for reducing Kepone levels in situ.

Elutriate Treatment

Bioconcentration and biodegradation are two areas that might show promise for treatment of elutriates. Bioconcentration is less desirable in that the Kepone is only being transferred to a different compartment. If in the process of bioconcentration a transfer is made to a compartment from which it is easier to dispose of the Kepone, then bioconcentration offers an advantage. Similarly, any bioconcentration which concentrates the Kepone above environmental concentrations may be of value. In addition, bioconcentration may offer indirect advantages such as disruption of the biological chain of contamination. Also bioconcentration might aid or enhance the degradation of Kepone.

Algae and fungi have been shown to concentrate many refractory organic compounds. Bacteria and fungi can be useful but they have drawbacks. The harvesting of the bacteria is the most difficult step and makes the utilization of bacteria, in what is otherwise an efficient system, impractical. Water hyacinths which are simple to harvest are not that efficient in accumulating organics. Therefore, algae and fungi would be preferred for use as free living organisms in a holding or treatment pond. Use of bacteria would involve biologic filters. These filters may contain either immobilized whole cells or extracts of membranes.

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* Plants do not accumulate organic compounds such as Kepone from sediments.

TABLE X.6. POSSIBILITIES FOR BIOLOGICAL AMELIORATION OF KEPONE IN BAILEY BAY

Organism	In Situ		Secondary Treatment	
	Water	Sediment	Water	Sediment
Higher plants e.g. (water hyacinth)	(1) Leaf surfaces may accumulate Kepone However, this is not a practical alternative	(1) Roots not known to accumulate similar compounds. Not feasible (Roots normally free floating)	(1) Surface area/volume required is prohibitive	(1) Not feasible
	(2) Not known to metabolize Kepone	(2) Not known to metabolize Kepone		
Fungi	(1) Because of low Kepone concentration in water the use of possible aerobic fungi which degrade Kepone is not feasible	(1) The sediments of Bailey Bay which are highly anaerobic and reducing will not permit the growth of the majority of fungi which are aerobic	(1) Aerobic Fungi would require large shallow ponds for degradation. May be necessary to achieve 100% degradation	(1) Not feasible
		(2) Anaerobes are not likely to be of any value	(2) Accumulation of Kepone by fungi used as biologic filters is possible	
Bacteria	(1) Because of low Kepone concentration effective degradation or accumulation may not be possible while the organisms can effectively accumulate Kepone many times, quantitatively the amounts removed would be small compared to current environmental levels.	(1) Anaerobes show best potential for dechlorination of Kepone in Bailey Bay sediments but no species have been identified	(1) Bacteria used as biologic filters is possible	(1) Anaerobic digesters show potential for optimization of degradation
			(2) Aerobes necessary to achieve 100% degradation	
Algae	(1) Low Kepone concentration reduces effectiveness of bioaccumulation while the organisms can effectively accumulate Kepone many times. Quantitatively the amounts removed would be small compared to current environmental levels.	(1) Not feasible (though algae can accumulate carbohydrates anaerobically)	(1) Have shown excellent bioaccumulation of similar compounds	(1) Not feasible
All of the above	Because of the many interactions possible, it is not possible to predict how all four would relate in order to achieve maximal amelioration. The following generalizations can be made: (1) Anaerobes and aerobes must interact so that optimum degradation will be achieved. (2) Normal organism antagonisms may decrease the possiblities of amelioriation.			

Secondary treatment facilities that relied on anaerobic digesters might provide a solution if anaerobes capable of attacking Kepone could be identified. An advantage of such a system over in situ degradation is that in a treatment facility many physical parameters can be controlled and a degree of optimization is possible. As noted earlier, some data have been reported suggesting that Kepone is degraded in the anaerobic sludge digestion process (Design Partnership, 1976).

A summary of the possible biologic alternatives that might be used to ameliorate the Kepone contamination of Bailey Bay is given in Table X.6. The higher plants and algae offer a means of concentrating Kepone in a form which can subsequently be harvested. This mechanism is largely restricted to soluble Kepone, however, and is of limited value since most Kepone resides in sediments. Uptake and concentration from sediments has not been demonstrated. Nor has bacterial degradation been demonstrated to date. Fungal species have been shown to be capable of degradation but are not competitive with natural biota and would be restricted to application in a controlled environment such as a treatment plant. In general then, to date, no biological approaches show promise for in situ amelioration and only fungal systems have shown promise for application to Kepone waste treatment in laboratory studies.

PHYSICAL-CHEMICAL ELUTRIATE AND SLURRY TREATMENT

Numerous means exist for the physical-chemical destruction of organic materials. A wide range of these were evaluated for application to Kepone contaminated water and sediments. Subsets of these include approaches designed around the use of oxidizing chemicals and processes utilizing electromagnetic waves of various frequencies.

Photochemical Degradation

The simplest option classified as physical-chemical destruction is photodegradation with sunlight. No data were found on the effect of electromagnetic radiation on Kepone degradation. Some work has been performed on Mirex. In these studies it was determined that Mirex is not subject to photolysis to any great extent (Brown et al., 1975; Carlson et al., 1976; Ivie et al., 1974). However, significant enhancement of the photolysis process was achieved when the Mirex was placed in an aliphatic amine solution (Brown et al., 1975). The decomposition product appeared to be a mixture of monohydride derivatives.

A set of simple exposure tests was designed to investigate the photolysis of Kepone in sediments exposed to sunlight. Closed systems were employed to keep a mass balance on the entire system (i.e., sediment, water from the sediment, and the atmosphere above the sediment) throughout the exposure period. Four enclosed dishes were constructed to test various modes of sunlight exposure:

- standard sediment - static,
- standard sediment with a flow-through system,
- standard sediment with a flow-through system plus weekly tilling,
- standard sediment covered with 1 in. of water.

The "landfarm" vessels were 30 cm x 20 cm x 7.6 cm (12 in. 8 in. x 3 in.) pyrex dishes with an 0.16 cm (1/16 in.) lucite cover. Each cover was perforated for insertion of: (1) a temperature probe, (2) an adsorptive column filled with XAD-4 resin or Filtrasorb activated carbon, and (3) a closed vent or tubing connected to a tubing pump for flow-through characteristics. The "landfarm" apparatus is illustrated in Figure X.2. The cover was sealed to the pyrex dishes and the "landfarms" were exposed to the sun for 12 weeks.

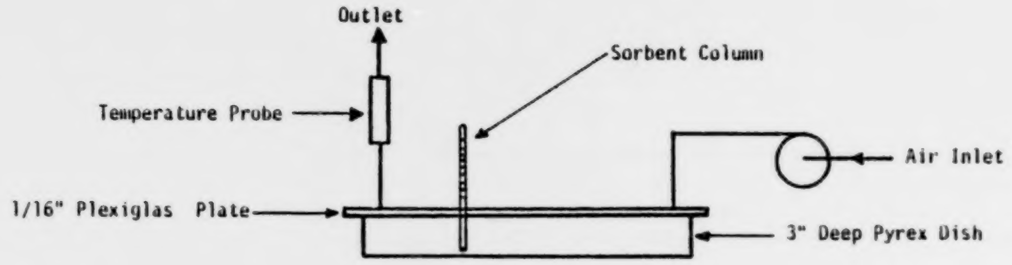

FIGURE X.2. Experimental Apparatus Employed in "Landfarm" Evaluations

In all cases, no significant changes in sediment Kepone content were recorded. Small amounts of Kepone were found in sorbent traps: 0.03 to 0.39 x 10^{-6} µg. This minor fraction of the total indicates a low level loss due to volatility (∿0.1%) but is overstated in that the plexiglas chambers caused a "green house" effect and sustained temperatures higher than ambient. The absence of a decrease in Kepone concentration also indicates a lack of degradation in the system. Hence, the studies both confirmed the persistency of Kepone in soils and sediments, and cast doubt on the efficacy of photochemical degradation using incident sunlight.

Amine Photosensitization

As noted previously, work with Mirex showed that, in the presence of ultraviolet light and an aliphatic amine, Mirex is apparently photosensitized and subsequently degraded. Since Mirex and Kepone are similar in structure, it was decided to test the effect of aliphatic amines on Kepone photodegradation.

To test the applicability of amines to Kepone degradation, 100 and 10% solutions of ethanolamine, triethylamine, and ethylenediamine were placed in quartz tubes, spiked with Kepone, and exposed to a photofloodlight for 1 hr or direct sunlight for 23 hr as illustrated in Figure X.3. Resultant

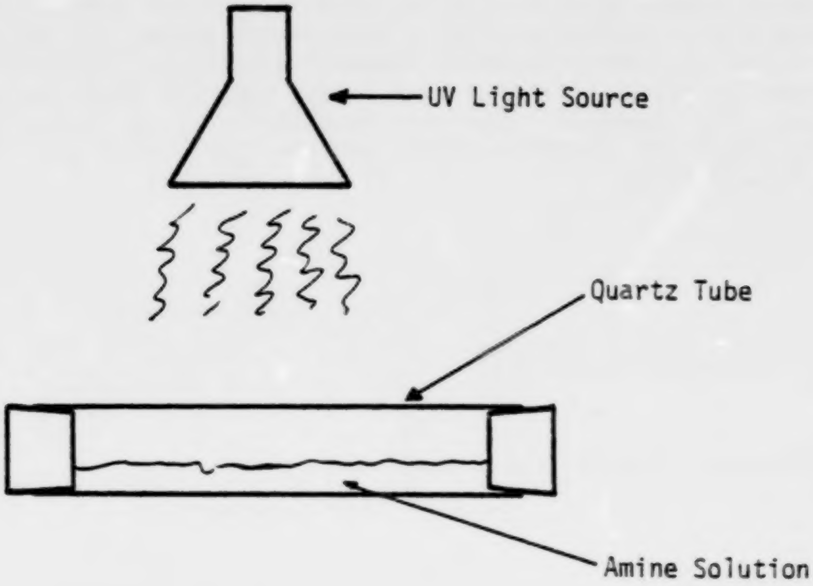

FIGURE X.3. Experimental Apparatus Employed to Test Amine Activated Photodegradation

levels of residual Kepone are presented in Table X.7. The amines apparently interferred with analysis such that absolute values are not as important as relative numbers in determining Kepone degradation. On this basis, the ethylenediamine demonstrates what appears to be a marked trend toward degradation.

TABLE X.7. EFFECTS OF SUNLAMP IRRADIATION ON AMINE SOLUTIONS

Solvent System	Strength of Solvent (%)	Kepone Concentration in ppb After Photoflood 1 hr	Kepone Concentration in ppb After Sunlight 23 hr
Hexane	10	1,640	6,040
	100	3,700	530
Ethanolamine	10	2,230	7,970
	100	6,520	2,530
Triethylamine	10	54.4	18,620
	100	2,240	477
Ethylenediamine	10	1,715	117
	100	<22.9	

Subsequently, a fourth solution using tert-butylamine was tested. Tert-butylamine is a large molecule which will resist the formation of complexes and any complications associated with complexation. With the "landfarm" apparatus, the presence of tert-butylamine was found to sponsor photochemical degradation leaving residual Kepone levels of 0.86 μg/g (ppm) from an initial sediment level of 1.27 μg/g (ppm). This constitutes a 32% reduction.

In a related test, a solution of ethylenediamine was sprayed on dry sediments contaminated at 0.95 μg/g (ppm) with Kepone and allowed to stand in the direct sun in an open beaker. After 10 days, the sediment was found to contain only 0.21 μg/g (ppm). This constitutes 78% destruction.

Due to the reliance on photolytic action, the approach here is limited to action at or very near the surface. It, therefore, may be of little use on the large volumes of contaminated spoils associated with any dredging activity. Continual tilling could circumvent some of these difficulties, but land area requirements would still be massive. On the other hand, the approach may be quite appropriate for use in the Hopewell area where soil has been contaminated by atmospheric deposition of windblown particulates. This option was considered separately in the preceding section on alternatives for Hopewell (Chapter IX). Caution is warranted, however, since no attempt has been made to identify degradation products or their toxicity.

Chlorine Dioxide

Chlorine dioxide is known as a powerful oxidizing agent capable of reacting with many organic compounds. The oxidant occurs as a gas at normal temperatures (25°C) but is produced as Oxine in a 2% aqueous solution by Biocide Chemicals of Norman, Oklahoma. That organization markets Oxine as an industrial and hospital disinfectant. Chlorine dioxide is toxic in pure form. When diluted, it dissociates into hypochlorous and oxygen ions. The oxidizing action results from reaction with the oxygen ion. Since low pH conditions stimulate dissociation, acid conditions are desirable. Ultraviolet radiation also appears beneficial.

Biocide has been successful in oxidizing phenolic materials with Oxine, suggesting that similar action on Kepone may occur. Consequently, a series of tests were conducted to measure specific oxidation of Kepone with Oxine. A 0.1 mg/ℓ (ppm) solution of Kepone in distilled water was split and adjusted to pH 1.7 and pH 7. These were then treated with sufficient Oxine to yield doses of 1:1 and 1:0.004 ClO_2:Kepone. Results are presented in Table X.8.

For the most part, the tests were negative. The apparent reduction in the one low pH solution is difficult to interpret since it corresponds to the lowest ClO_2 dose. A second set of tests was initiated to extend this information to contaminated sediments and to test the increased efficiency available from exposure to sunlight. In this case, 500 g (1.1 lb) standard

TABLE X.8. KEPONE RESIDUALS (μg/ℓ - ppb) AFTER APPLICATION OF ClO_2

	ClO_2 Dose (mg/ℓ - ppm)	
pH	0.1	0.004
1.7	75.2	8.2
7.0	74.9	71.1
Blank	66	66

Bailey Bay sediments (1.17 μg/g-ppm Kepone) were treated with 100 ml (34 oz) of 2% and 1% Oxines and allowed to stand in the sunlight for 1 week. Subsequent analyses revealed 1.07 and 1.34 μg/g (ppm) Kepone in the 2 and 1% tests, respectively. This constitutes an average of less than 10% reduction in Kepone. The apparent increase in Kepone during this exposure is believed to represent an analytical anomaly. The results reflect sampling differences rather than degradation. In either case, the oxidizing action is nonspecific and too limited to warrant its application to the Hopewell problem at this time.

Ozonation

Ozone, like chlorine dioxide, is noted for its ability to oxidize materials. Ozonation has been employed in a variety of applications such as disinfection of wastewaters and accelerated oxidation of wastewaters in an activated sludge configuration. The ozone itself leaves no noxious residues. It has been hypothesized that ozone could be used to oxidize Kepone in a similar fashion either through forced contact in situ or through confined treatment in a process configuration.

To evaluate the above possibilities, a contact vessel was arranged to allow ozone to bubble through sediments contaminated at 1 μg/g (ppm). After 4 hr of such contact, no reduction in Kepone was noted. This confirms similar work by Ralph Valentine at Atlantic Research. Atlantic Research has also noted, however, that ozonation of chlorinated hydrocarbons is facilitated by concurrent irradiation with ultraviolet light.

Research on combined ozonation and ultraviolet irradiation has been most fully explored by Westgate Research Corporation in West Los Angeles. There a small facility capable of treating solutions in this configuration has been produced. To test its applicability to the treatment of Kepone, a solution of 5.172 mg/ℓ (ppm) Kepone was submitted for treatment. Subsequent effluent samples were found to contain 20.9 μg/ℓ (ppb) after a batch exposure period of 1.5 hr.

As noted previously, ultraviolet irradiation processes are limited in that degradation can occur only at exposed surfaces receiving direct irradiation. Hence, these results will not necessarily translate to solids or slurry systems and may in fact be greatly affected by the presence of solids or turbidity in natural waters. This is illustrated by results presented in Table X.9. The addition of carbon particles to synthetic scrubber waters reduced removal in both the 1- and 2-hr exposure periods. Work on turbid waters is continuing at Westgate Research.

TABLE X.9. EFFECT OF WESTGATE PROCESS ON SYNTHETIC SCRUBBER WATER

	Exposure Period, hr	Residuals Level, μg/ℓ		Removal %, hr	
	0	1	2	1	2
Clear Solution	11,415	1,765	476	85	96
With Carbon Particles	10,300	2,000	1,056	81	90

In studies with wastewater effluent from the Hopewell sewage treatment plant, UV-ozonalysis was found quite effective for reduction of Kepone levels as noted in Table X.10.

TABLE X.10. THE EFFECT OF UV-OZONALYSIS ON THE KEPONE LEVEL IN WASTEWATER EFFLUENT FROM THE HOPEWELL SEWAGE TREATMENT PLANT

Exposure Period, minutes	Kepone Concentration, μg/ℓ (ppb)	Removal, %
0	0.77	--
15	0.66	14
30	0.24	69
45	0.11	86
60	0.096	88

Based on these data, it is concluded that the Westgate process is effective in reducing Kepone levels in aqueous media and could be an effective means of treatment for elutriate, wastewater, and contaminated natural waters. However, it should be noted that no attempt was made to identify degradation products or their potential toxicity.

Cost projections developed by Westgate Research indicate a capital cost of \$125 to 140,000/MGD capacity and operating and maintenance costs (including amortization) of \$0.11 to 0.12/1000 gallons treated. Details of estimates for use of the Westgate system to remove 1 μg/ℓ (ppm) Kepone from runoff water are given in Tables X.11 through X.15.

TABLE X.11. PRELIMINARY COST ANALYSIS FOR ULTROX SYSTEM (COURTESY OF WESTATE RESEARCH CORPORATION, 1977)

ULTROX® Treatment Plants (Automated)
to Remove 1 μg/ℓ Kepone from Runoff Water

Summary

Capital Cost	50 mgd	100 mgd	150 mgd
ULTROX® Plant Installed, including Engineering	\$7,920,000	\$14,610,000	\$19,030,000
\$/gal/min	228	210	183
Annual O&M Costs			
Amortization (8% - 10 yr)	\$ 855,000	\$ 1,580,000	\$ 2,055,000
Ozone Generation Power Cost	307,000	606,000	913,000
UV Light Power Cost	438,000	876,000	1,314,000
Maintenance Cost	631,000	1,300,000	1,800,000
TOTAL	\$2,231,000	\$ 4,362,000	\$ 6,082,000
O&M Cost/1000 gal	\$0.12	\$0.12	\$0.11

If a small capacity elutriate treatment plant were constructed, unit costs would increase considerably. For a 3 MGD plant, the capital costs are \$1,353,000 (\$438,000/MGD treated) and the operating costs are \$0.23/1000 gallons (\$0.14/1000 gal amortization, \$0.051/1000 gal maintenance).

Radiation

Oxidation can also be achieved through direct bombardment with radiation. Given a sufficient dose, virtually all organic materials can be carbonized. The specific action results from excitation of molecular bonds to a point where the bond breaks. No toxic residues are produced when carbonization is carried to completion, as a physical destruction methodology.

TABLE X.12. CAPITAL COST FOR ULTROX SYSTEM (COURTESY OF WESTGATE RESEARCH CORPORATION, 1977)

Design	50 mgd	100 mgd	150 mgd
Reactor Res Time	30 min	30 min	30 min
Flow	34,700 gpm	69,400 gpm	104,200 gpm
ULTROX Basin Vol.	139,000 ft^3	278,000 ft^3	417,000 ft^3
ULTROX Basin Size (ft)	70 x 140 x 15	100 x 200 x 15	120 x 240 x 15
No. of STAC's (3x)	3,200	6,400	9,600
Ozone Gen	4,200 lb/day	8,300 lb/day	12,500 lb/day
Basin (installed)	$ 300,000	$ 600,000	$ 900,000
ULTROX STAC's	4,320,000	7,680,000	9,600,000
Ozone Generator	2,000,000	3,800,000	5,000,000
Electrical	100,000	200,000	300,000
Misc	500,000	1,000,000	1,500,000
Engineering	700,000	1,330,000	1,730,000
TOTAL	$7,920,000	$14,610,000	$19,030,000

TABLE X.13. OZONE GENERATION POWER COST (COURTESY OF WESTGATE RESEARCH CORPORATION, 1977)

	50 mgd	100 mgd	150 mgd
$\frac{lb}{day} O_3$	4,200	8,300	12,500
Installed kW	1,750	3,460	5,210
$\frac{kWh}{day}$ for O_3 prod	42,000	83,000	125,000
$\frac{cost}{day}$ @ $0.02/kWh	$840	$1,660	$2,500

TABLE X.14. UV LIGHT POWER COST (COURTESY OF WESTGATE RESEARCH CORPORATION, 1977)

	50 mgd	100 mgd	150 mgd
No. of 65w Lamps	38,400	76,800	115,200
Installed kW	2,500	5,000	7,500
$\frac{\text{kWh}}{\text{day}}$ for UV	60,000	120,000	180,000
$\frac{\text{cost}}{\text{day}}$ @ \$0.02/kWh	\$1,200	\$2,400	\$3,600

TABLE X.15. MONITORING AND MAINTENANCE COST FOR ULTROX SYSTEM (COURTESY OF WESTGATE RESEARCH CORPORATION, 1977)

	50 mgd	100 mgd	150 mgd
UV Lamp Replacement Ave. Cost/day	\$1,580	\$3,160	\$4,420
Monitoring & Maint. Labor & Misc. Parts Ave. Cost/day	150	300	450
	\$1,730	\$3,460	\$4,870

To evaluate the use of radiation for destruction of Kepone, standard Bailey Bay sediments containing 1.17 μg/g (ppm) Kepone were placed in glass containers and exposed to varying amounts of γ radiation. Results are given in Table X.16.

While effective removal can be obtained, large doses are required, and gas chromatographs revealed the presence of a large peak representing degradation product. The latter appears to be partially dechlorinated Kepone, but positive identification was not made.

TABLE X.16. EFFECTS OF γ RADIATION ON KEPONE CONCENTRATIONS IN SEDIMENT

Dose, megarod	Residual Kepone, μg/g	Removal, %
0	1.2	--
1	0.58	52
10	0.51	57
54.7	0.15	87
144	0.035	97

As an initial appraisal it appears that degradation efficiencies are a function of radiation penetration. The vials used in this test were 2.5 cm (1 in.) diameter containers with an effective 1.3 cm (1/2 in.) penetration radius. If the penetration distance can be reduced, the degradation efficiency can go up. At the present time there insufficient data are available to pursue radiation as an immediate treatment process. Further evaluations of penetration distances and dose may result in an effective unit operation for Kepone amelioration.

Related work has been performed by the Massachusetts Institute of Technology using electron beam radiation (Trump, 1977). While this work was largely focused on disinfection of municipal sludges, some analytical work was performed to determine the effects of the electron beam bombardment on toxic constituents. High pressure liquid chromatography revealed that 3, 4, 2' PCB, monochloro PCB, and Monuron at saturation levels in water are totally destroyed when irradiated at dose levels as low as 10 kilorads. PCB in a solution with 0.5% soap was virtually eliminated by a dose of 400 kilorads. This suggests that positive results may also be obtained with more highly chlorinated organics such as Kepone. No investigations with an electron beam source have been conducted to date, however. Consequently, no definitive appraisal of effectiveness can be made at this time.

Catalytic Reduction

It has been suggested that one means of destroying chlorinated hydrocarbons would be the use of catalysts to facilitate reduction of the chlorine functional groups to free ionic chloride in solution. This would leave behind a bare organic skeleton less toxic and more amenable to biochemical attack. Envirogenics is studying such a process for the destruction of PCBs and Kepone. This approach utilizes a copper-iron catalyst in a reductive column with sand as the working substrate. Contaminated wastewaters are put through the column at a low pH and allowed to undergo reduction at the halogenated sites.

Initial reports indicated a high level of success. Subsequent analysis, however, has reduced optimism considerably. Original plans for implementation at General Electric in upstate New York have been terminated. Researchers there report that what had been thought to be PCB removal appears now to have been adsorption of PCBs on the substrate. Once capacity is reached, the column is no longer capable of removal (Griffen, 1977). Similar results have been seen at the EPA Gulf Breeze Laboratory. When reduction was observed it was only partial and left many halogenated residues. Work conducted on Kepone for the EPA revealed similar patterns of numerous by-product peaks. Attempts to obtain samples for independent evaluation have been unsuccessful. Due to these negative findings, the approach was abandoned from further consideration.

CARBON ADSORPTION

During the decontamination efforts in early 1976, the EPA mobile spill treatment trailer was brought to Hopewell to help decontaminate washwaters and liquid wastes. At that time it was noted that carbon adsorption was effective in removing Kepone from solution. Because of this prior work, no specific laboratory studies were conducted on activated carbon applications to elutriate waters. However, adsorption isotherms produced during evaluation of sorbents for in situ application confirm the efficacy of this approach. Therefore, this option is considered viable if treatment facilities are to be constructed. Specific data on carbon capacity for Kepone are given in subsequent sections on sorbents.

Several of the engineering options for Bailey Bay developed by the Corps of Engineers may require a treatment facility to remove Kepone from contaminated runoff. The size of such a facility would depend on the size of the holding reservoir and the desired drawdown time. A detailed breakdown of unit process sizes for various components of a granular activated carbon treatment plant is given in Table X.17. Associated capital costs are presented in Table X.18. Operating and maintenance costs for a 50 MGD plant are given in Table X.19.

Field studies have revealed that Kepone in Bailey Creek is largely associated with particulate matter. Consequently, some degree of treatment can be achieved by construction of coagulation facilities to remove solids with no subsequent carbon adsorption. If this approach is taken, costs are reduced substantially as illustrated in Tables X.20 through X.22. Costs are compared in Table X.23. However, it must be repeated that transport out of Bailey Bay and down the James River is dependent on soluble Kepone. Hence, solids removal will not be universally effective.

Both carbon adsorption and solids removal are directed to removal from water. They do not constitute disposal. Disposal is accomplished with activated carbon if regeneration is employed in a furnace capable of destroying Kepone, otherwise, additional processing or burial is required.

TABLE X.17. GRANULAR CARBON SYSTEMS UNIT PROCESS SIZES*

	MGD				
	1	5	10	25	50
Rapid Mix, ft^3	93	465	930	2,325	4,650
Flocculator, ft^3	1,395	6,975	13,950	34,875	69,750
Clarifier, ft^2	1,302	6,510	13,020	32,550	65,100
Filter, ft^2	140	700	1,400	3,500	7,000
Primary Sludge					
Thickener, ft^2	207	1,035	2,070	5,175	10,350
Vacuum Filter, ft^2	37	185	370	925	1,850
Incinerator, ft^2	50	250	500	1,250	2,500
Chemical Feed					
Wastewater					
Alum, lb/hr	45	225	450	1,125	2,250
Poly, lb/hr	0.09	0.45	0.90	2.25	4.50
Primary Sludge					
Lime, lb/hr	35	175	350	875	1,750
Primary Sludge Pumping, gpm	20	100	200	500	1,000
Carbon Influent Pumping, MGD	1.5	8.5	15	37.5	75
Effective Carbon Contactor Vol., ft^3	3,069	15,345	30,690	76,725	153,450
Carbon Regeneration Furnace, ft^2	75(1)	270	540	1,350	2,700

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*Minimum size furnace. Run 50% of time. Ref. Shudrow, A. J. and G. L. Culp, "Appraisal of Powdered Activated Carbon Processes for Municipal Waste Water Treatment," Environmental Protection Technology Series EPA-600/2-77-156. September 1977.

TABLE X.18. CAPITAL COST FOR GRANULAR CARBON SYSTEMS

	1 mgd	5 mgd	10 mgd	25 mgd	50 mgd
Pretreatment	1,665,770	3,632,680	5,323,340	8,854,060	14,134,720
Carbon	1,713,190	3,272,260	5,192,930	10,148,740	15,400,000
Subtotal	3,378,960	6,904,940	10,516,300	19,002,800	29,534,700
Yardwork	565,531	993,533	1,511,640	2,728,070	4,641,620
Total Construction Cost	3,944,490	7,898,470	12,027,900	21,730,900	34,176,300
Eng. Fiscal Legal	552,422	970,864	1,477,210	2,665,893	4,962,000
Interest During Construction	410,368	808,579	1,231,008	2,221,577	4,135,017
Total Capital Cost with Pretreatment	4,907,300	9,677,910	14,736,100	26,618,400	43,273,300
Total Capital Cost Without Pretreatment	3,241,530	5,945,230	9,412,760	17,764,340	29,138,580

TABLE X.19. OPERATING AND MAINTENANCE COSTS FOR A 50 MGD GRANULATED ACTIVATED CARBON TREATMENT PLANT

	Annual Labor, hr	Cost-Labor at $15/hr	Annual Power Consumption, kW/hr	Cost Power at 0.02/kW/hr	Annual Fuel Consumption, SCF	Cost-Fuel at $2/SCF	Annual Cost of Maintenance	Total Annual Cost of Unit Operation
Rapid Mix	800	$ 12,000	1,200,000	$24,000			$ 3,424	$ 39,424
Flocculator	350	5,250	80,000	1,600			4,769	11,619
Clarifier	5,000	75,000	13,200	264			12,229	87,493
Filter	8,000	120,000	27,000	540			24,458	144,998
Primary Sludge Thickness	1,100	16,500	26,000	520			2,568	19,588
Vacuum Filter	16,000	240,000	1,500,000	30,000			122,290	392,290
Incinerator	18,000	270,000	1,750,000	35,000	130×10^6	$260,000	36,687	601,687
Chemical Feed Alum	2,000	30,000	6,000	120			2,445	32,565
Polymer	240	6,300	5,000	100			465	6,865
Primary Sludge Lime Feed	2,700	40,500	52,000	1,040			3,424	44,964
Sludge Pumping Primary Sludge	400	6,000	230,000	4,600			12,229	22,829
Subtotal Pretreatment	54,590	821,550	4,889,200	97,784	130×10^6	260,000	224,988	1,404,322
Carbon Adsorption	6,000	90,000	3,500,000	70,000			14,087	174,087
Carbon Regeneration	19,000	285,000	1,600,000	32,000	181×10^6	362,000	19,566	698,566
Subtotal Carbon Treatment	25,000	375,000	5,100,000	102,000	181×10^6	362,000	33,653	872,653
Total Treatment	79,590	$1,196,550	9,989,200	$199,784	311×10^6	$622,000	$258,641	$2,276,975

TABLE X.20. SIZING REQUIREMENTS FOR SOLIDS REMOVAL SYSTEM

Unit Process or Component	Coagulation 1	5	10	25	50
Primary Sedimentation (ft^2)	1,250	6,250	12,500	31,250	62,500
Rapid Mixing (ft^3)	93	465	930	2,325	4,650
Flocculation (ft^2)	1,395	6,975	13,950	34,875	69,750
Clarifier (ft^2)	1,302	6,510	13,020	32,550	65,100
Primary Sludge Pumping (gpm)	15	75	150	375	750
Chemical Sludge Pumping (gpm)	5	25	50	125	250
Gravity Thickening (ft^2)	253	825	1,650	4,125	8,250
Vacuum Filtration (ft^2)	113	210	420	1,050	2,100

TABLE X.21. CAPITAL COSTS FOR SOLIDS REMOVAL SYSTEM

Fourth Quarter, 1975 (June)

Process Component	Coagulation - Capital Costs, MGD 1	5	10	25	50
Primary Sedimentation Tanks	70,000	260,000	440,000	940,000	1,600,000
Rapid Mixing	10,000	23,000	37,000	76,000	130,000
Flocculation	13,000	38,000	55,000	100,000	160,000
Clarifier	85,000	230,000	440,000	1,100,000	2,200,000
Primary Sludge Pumping	44,000	93,000	140,000	200,000	290,000
Chemical Sludge Pumping	40,000	70,000	100,000	170,000	220,000
Gravity Thickener	70,000	105,000	130,000	180,000	230,000
Vacuum Filter	200,000	280,000	420,000	800,000	1,300,000
Subtotal	532,000	1,099,000	1,762,000	3,566,000	6,130,000
Yardwork	74,530	153,835	246,606	499,090	858,183
Total Construction Cost June 1975	606,530	1,252,835	2,008,606	4,065,090	6,988,183
Total Estimate August 1977 (Cost index ratio 1.1856)	719,102	1,485,361	2,381,403	4,819,571	8,285,190
Engineering, Fiscal, Legal	86,292	178,243	285,768	578,349	995,223
Interest During Construction	71,910	148,536	238,140	481,957	828,519
TOTAL CAPITAL COST	877,304	1,812,140	2,905,311	5,879,877	10,107,932

TABLE X.22. PLANT MAINTENANCE COST FOR 50 MGD COAGULATION

Process Component	Annual Labor, hr	Annual Power Consumption, kWhr	Annual Cost of Maintenance Materials, $
Primary Sedimentation Tanks	4,900	20,000	9,500
Rapid Mixing	800	1,200,000	2,800
Flocculation	350	80,000	3,900
Clarifier	5,000	13,200	10,000
Primary Sludge Pumping	340	15,000	9,000
Chemical Sludge Pumping	220	66,000	4,000
Gravity Thickening	1,400	12,000	1,800
Vacuum Filtration	14,000	1,400,000	105,000
	27,010	2,806,200	June 1975 451,100
		Estimate for August 1977 (Material cost index ratio 1.2229)	551,650

TABLE X.23. COST COMPARISON FOR A 50 MGD ACTIVATED CARBON FACILITY AND A 50 MGD SOLIDS REMOVAL FACILITY

	Granular Carbon	Coagulation
Total Construction Costs (August 1977)	41,350,171	8,285,190
Engineering, Fiscal, Legal	4,962,020	994,223
Interest During Construction	4,135,017	828,519
Total Capital Costs	50,447,208	10,107,932
Annual Operating Materials Costs	262,924	551,650

IN SITU PROCESS

In situ processes as a category are the newest of the approaches to removal/mitigation of in-place toxic materials. As such, they are understandably less fully developed than other approaches, and may offer benefits as yet unmeasured. Several of the more promising options were selected for testing in the laboratory. As noted previously, biological approaches appear to offer little with respect to the removal of Kepone from the James River System. Work, therefore, focused on two types of approaches: use of sorbents and use of polymer films.

Sorbents

Natural sorbents such as activated carbon and synthetic sorbents such as the macroreticular resins have been shown to be effective in concentrating organics similar to Kepone. In that process, sorbents act much as natural sediments do in maintaining levels of Kepone much higher than those in adjacent waters. At equilibrium, a dynamic system of sorption and desorption comes to balance such that sorbed molecules of Kepone leaving the substrate are just offset by the molecules of dissolved Kepone being adsorbed. The magnitude of the difference in water and substrate concentrations -- the partition coefficient or K_d -- is a function of the ratio of the sorption and desorption rate constants. Substrates with different characteristic sorption-desorption rate constants will display a different partition coefficient. Consequently, some media can maintain high levels of Kepone without commensurately higher levels of dissolved Kepone in the adjacent waters while others cannot. Materials capable of numerically smaller partition values (concentration in water:concentration in substrate) than those exhibited by natural sediments will therefore reduce the levels of dissolved Kepone in the water if introduced to the system by establishing a three-phase equilibrium with the highest concentrations of Kepone on the new material, a lower concentration on the sediment, and the lowest concentration in the water.

The use of sorbents is based on this phenomenon. Selective or strongly sorbent media can be placed in a natural system to effectively reduce dissolved levels of contaminant and create a new equilibrium partition between water and solids. The lower dissolved levels then stimulate desorption from contaminated sediments as the system moves to a new equilibrium state. Desorption will continue until all three phases reach concentrations which maintain the constant partition ratios between any two phases. This approach has been attempted using powdered activated carbon to prevent water supply contamination in a reservoir (Hyndshaw, 1969). The efficacy of a similar approach to the Kepone problem is dependent on the nature of the sorbent selected and its specific action for Kepone.

To screen media for application in areas where sediments are contaminated with Kepone, candidate sorbents were employed in batch adsorption evaluations. The evaluations were conducted using dilutions mixed from a stock Kepone solution (116 mg Kepone in >12 pH caustic -- 100 mg/ℓ -ppm). Aliquots of stock solution were added to distilled water and brought up to 200 ml (0.053 gal) volume in a 500 ml (0.132 gal) glass bottle. Concentrated HCl was added to bring the pH to 7. A 1 gram sample of sorbent was then added to each bottle and entire apparatus placed on a horizontal displacement shaker for 24 hr. Samples were then removed, filtered through μ Gelman glass filters and analyzed. Results of these batch adsorption tests are presented in Table X.24.

TABLE X.24. REMOVAL CAPABILITIES OF SORBENTS TESTED FOR KEPONE SORPTION

Sorbent	Residual ppb	% Removal	Partition $\left(\frac{\text{Con. in Water}}{\text{Con. in Sorbent}}\right)$
Blank	3374	--	
ES 863*	2.86	99.9	4.2×10^{-6}
C 464*	705	79.1	1.3×10^{-3}
S 37*	812	75.9	1.5×10^{-3}
S 761*	1071	68.3	2.3×10^{-3}
XAD-7**	50.2	98.5	7.5×10^{-5}
XAD-4**	3.15	99.9	4.7×10^{-6}
XAD-2**	4.99	99.8	7.4×10^{-6}
Carbon Microballoons+	1283	61.9	3.1×10^{-3}
Filtrasorb 3000++	3.21	99.9	4.8×10^{-6}
Magnetic ES863	18.0	99.5	2.7×10^{-5}
Blank II	2400	--	
Anthracite	1515	37	8.5×10^{-3}
Hi Volatile Bituminous	2010	16	2.6×10^{-2}
Subbituminous	1520	37	8.6×10^{-3}
Lignite	607	75	1.7×10^{-3}
Blank III	765	--	
Ambersorb XE	17.9	98	1.2×10^{-4}

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* Product of Diamond Shamrock
** Product of Rohm and Haas
+ Product of Bently Laboratories
++ Product of Calgon

Based on these results, ES863, XAD-4, XAD-2, and Filtrasorb 300 were selected for further study. The three synthetic products are macroreticular synthetic sorbents produced commercially. The Filtrasorb 300 is a commercial activated carbon. In addition to these, a specialty carbon product formed around iron particles became available in time for subsequent evaluations. Allied Chemical had also performed work on anthracite coal.

As noted earlier, sorbents applied to sediments in situ are capable of reducing the availability of a material to the water column, but they do not destroy or remove the contaminant. Removal can be achieved, however, if media are made to be retrievable. Work at Battelle indicates that this is possible through the inclusion of magnetite or iron particles in the sorbent matrix which will render the media particles susceptible to magnetic fields.

Recognizing this potential for actual removal of Kepone with sorbents, subsequent experiments were designed to evaluate sorbents in a way which would predict effectiveness for a retrievable design. This was achieved through use of a series of test aquariums. A 500 ml (0.232 gal) sample of "standard" Bailey Bay sediment (1.17 mg/ℓ ppm Kepone) was placed in each 2000 ml beaker and covered with 1000 ml of water as illustrated in Figure X.4. A set of beakers was designated for each sorbent and for control purposes so that a discrete group of beakers could be sacrificed at the end of each observation period. Each sorbent beaker received 5 g of sorbent and was allowed to sit for 2 weeks. At that time, the first group of beakers (a control and one for each of the sorbents) was sacrificed for analysis. Sorbents were then mixed down into the sediment in the remaining beakers for the 4, 8, and 12-week analyses. Results of sediment analysis after sacrifice and removal of sorbents are presented in Table X.25. The transfer of Kepone from sediments to sorbents was verified through analysis of regenerate solutions for each sorbent.

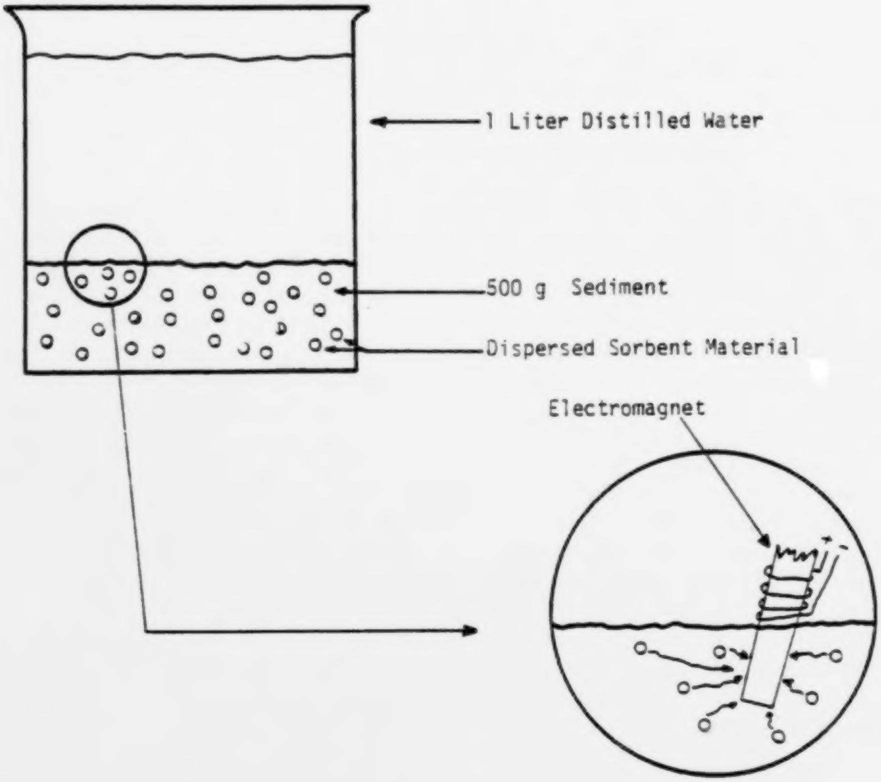

FIGURE X.4. Beaker Test Showing Sediment, Sorbent, and Water Representation of Magnetic Retrieval of Sorbent Using Electromagnet

TABLE X.25. EFFECTIVENESS OF SORBENTS IN ACCUMULATING KEPONE FROM BAILEY BAY SEDIMENTS

	Kepone Concentration in Sediments, µg/g-ppm						
Sorbent	2 wk	4 wk	8 wk	12 wk	Maximum Removal %	Maximum Theoretical Removal, %	Percent of Maximum Theoretical Removal Achieved, %
XAD-2*	0.80	0.53	1.19		65	60	100+
XAD-4*	1.18	1.06	0.99		32	67	48
863**	0.89	0.72	1.21		54	72	75
FILTRASORB+	1.21	1.06	1.00	1.33	32	67	48
Magnetic Carbon	1.56	1.23	1.24	1.04++	21	--	--
Blank	1.56	1.56	1.16		--	--	--
Magnetic 863	0.77		0.82		31	25	100+
Blank	0.92		1.18		--	--	--

---

* Product of Rohm and Haas

** Product of Diamond Shamrock

+ Product of Calgon

++ Analysis of the spent carbon revealed 1.07 µg/g Kepone

Insufficient time was available to prepare magnetically retrievable sorbents other than the one magnetic carbon and the ES863. Consequently, other means of separation were needed to proceed with the analysis of sediments and sorbent regenerant solutions. During the course of work it was found that the most satisfactory method of removing synthetic sorbents from the sediment was to draw off all water, then dry the sediment at 103°C. This caused the resin beads to dehydrate. It was then possible to rewet the sediment and resin. Due to differences in wetting kinetics, the sediment would sink, but the resin would float. The floating resin was then skimmed from the top of the liquid. Once the floating layer was removed the resin was again dried and residual media separated from floating sediments by rolling the spherical resin beads away from the irregular sediment particles. The magnetic carbon and resin were removed with electromagnets as illustrated in Figure X.4. Filtrasorb was removed manually.

Based on the partition coefficients calculated for Bailey Bay sediments and the sorbents used, it is possible to predict the maximum theoretical removal and residual sediment levels for each sorbent. This is accomplished in the following manner:

1) Consider A, B, and C as the unknown concentration of Kepone in each phase at equilibrium: A is Kepone in sediment (µg/g); B is Kepone in water (µg/ℓ); and C is Kepone in media (µg/g).

2) Construct the three known relations for these unknowns:

   a) B/A = partition coefficient for Bailey Bay sediments
   b) B/C = partition coefficient for media
   c) AX (mass of sediments) + BX (volume of water) + CX (mass of media) = total Kepone in system.

3) Solve for the three equilibrium concentrations.

To illustrate, consider the use of XAD-4 in the aquarium studies employed here. The partition coefficient for Bailey Bay sediments has been observed to be 5×10^{-4}. Hence:

$$B/A = 5 \times 10^{-4}.$$

The partition coefficient for XAD-4 is approximately 5×10^{-6}, therefore:

$$B/C = 5 \times 10^{-6}.$$

The aquarium contained 250 g of dry sediments, 1.5 ℓ of water, and 5 g of XAD-4. Total Kepone was 250 μg. Hence:

$$250\ A + 1.5\ B + 5\ C = 250.$$

Solving the three simultaneous equations, it can be determined that at equilibrium, Kepone concentrations will be:

0.33 μg/g (ppm) in sediment
0.165 ng/ℓ (pptr) in water
33.0 μg/g (ppm) in media

This constitutes 66% removal with a single application. In like fashion, theoretical maximum removal concentrations have been predicted for each media employed in the aquarium studies. These are reported in Table X.25. Reviewing these data, it is apparent that the XAD-2 and magnetic 863 came closest to reaching their theoretical limits. It should be noted that the inclusion of magnetite in the magnetic 863 adds significant weight to the particles. Therefore, the weighed amount of resin added to tests is misleading since it is not the weight of active resin but includes the magnetite (30% by weight). On a weight of resin basin, the magnetic 863 is comparable to commercial grade ES863.

A key to the effectiveness of use of sorbents, the nature of equipment which would be needed for application, and the dose requirements of sediments lies in the distance over which the media can accumulate the contaminant. As contaminant is depleted around an individual sorbent particle, a gradient is established across which the contaminant will move. Without mixing, the migration soon becomes the rate limiting feature and accumulation slows considerably. If media is applied only to the surface of the contaminated sediments, these rates will ultimately determine the depth to which contaminant levels will be depleted.

To investigate these parameters, three 18-in. segments of 5 cm (2 in.) diameter cellulose acetyl butyrate cylinders were charged with standard Bailey Bay sediments (1.17 μg/g-ppm Kepone) placed on a clay plug. The columns were covered with 15 cm (6 in.) of distilled water. One column was selected as a blank. The remaining two were treated with 1 g of XAD-4 and 863 sorbents. (The XAD-4 resin was selected prior to receipt of aquarium results and does not reflect its performance relative to XAD-2). Relative proportions are illustrated in Figure X.5. The sorbent loadings constituted 1 g of media to 490 g sediment or 1 g of media to 573 μg Kepone. After 8 weeks, columns were frozen and cut into 1.3 cm (0.5 in.) segments for analysis. Results are presented in Table X.26.

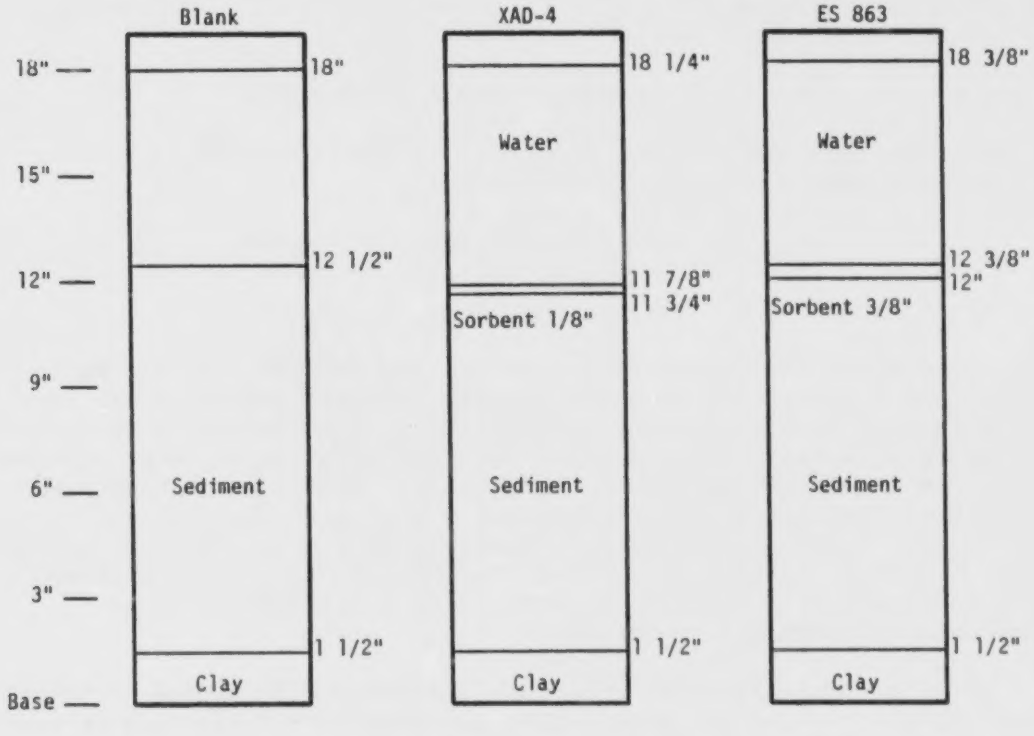
Blank
XAD-4
ES 863
18"
15"
12"
9"
6"
3"
Base
18"
12 1/2"
1 1/2"
Sediment
Clay
18 1/4"
Water
11 7/8"
11 3/4"
Sorbent 1/8"
Sediment
1 1/2"
Clay
18 3/8"
Water
12 3/8"
12"
Sorbent 3/8"
Sediment
1 1/2"
Clay

FIGURE X.5. Dimensions Employed in Verticle Column Tests for Sorbents

TABLE X.26. EFFECT OF SURFACE APPLICATION OF SORBENTS WITH DEPTH

Depth, in.	Blank Kepone Content, ppm	Sorbent ES863[a] Kepone Content, ppm	Sorbent ES863[a] Apparent % Removal	XAD-4[b] Kepone Content, ppm	XAD-4[b] Apparent % Removal
0.5		0.25	59	1.11	--
1.0	0.61	0.27	56	0.44	28
1.5		0.27	36	0.40	5
2.0	0.42	0.64	--	0.42	--
2.5		0.24	43	0.20	52
3.0		0.58	--	0.32	24
3.5		0.10	76	0.48	--
4.0				0.24	43
4.5				0.53	--
5.0				0.34	19
5.5				0.44	--
6.0				0.53	--
Clay Support	0.58				

(a) Product of Diamond Shamrock
(b) Product of Rohm and Haas

The ES863 displays an ability to effect Kepone concentrations at a distance. The XAD-4 performance is lower than that for ES863 just as it was lower in the aquarium studies and is believed to reflect inhomogeneity in sampling rather than removal. Hence, surface application should be adequate for treatment of shallow contamination in sediments. Deeper contamination would require that media be mixed in.

During the course of the laboratory work, Diamond Shamrock produced a sample of magnetically retrievable ES863 by incorporating iron in the sorbent matrix during production. Subsequent testing revealed that the media is readily retrieved through use of an electromagnet. Recovery is best when retrieval is performed on slurried sediments rather than dried sediments. In the latter case, extraneous matter is trapped among the particles and retrieved along with the sorbent. In either case, natural magnetite and iron are retrieved along with the media.

The magnetic carbon test in the laboratory was produced by blending carbon coating mix, a proprietary product of Union Carbide, with ferric-ferrous oxide black. The coating mix contains a silicate base binder which solidifies upon drying. If initial drying is performed at 103°C, the product can easily be crushed to the desired size. Curing at 160 to 180°C then sets the product into a hard form resistant to attack by water.

As noted earlier, Allied conducted laboratory investigations with anthracite coal as an inexpensive sorbent. Results of this work have been reported by Paterson et al. (1977). Initially, Allied researchers determined that Kepone is removed from solution by coal and that the removal, while slow, will continue for at least 28 days. At that time, removal had reached 70%. Details of subsequent tests are presented in Table X.27.

TABLE X.27. EFFECT OF ANTHRACITE COAL ON KEPONE CONCENTRATIONS IN WATER (PATERSON et al., 1977)

Initial Kepone Concentration	Particle Size Anthracite	Time	% Reduction	Stirring
96 ppb	-8, +14 mesh	4 days	24%	3 hr
96 ppb	-8, +14 mesh	12 days	35%	3 hr
1.9 ppb	-8, +14 mesh	15 min	20%	15 min
1.9 ppb	-8, +14 mesh	3 hr	40%	3 hr
1.9 ppb	-8, +14 mesh	1 day	55%	1.5 hr
1.9 ppb	-8, +14 mesh	7 days	65%	1.5 hr
1.9 ppb	-8, +14 mesh	15 days	72%	1.5 hr

A second set of evaluations was conducted with James River sediments spiked with ^{14}C labeled Kepone. Here the procedure involved adding antracite granules to the surface of the sediment and monitoring the effect in resulting concentrations of Kepone in the water column. Results are summarized in Table X.28.

TABLE X.28. EFFECT OF SURFICIAL APPLICATION OF COAL TO KEPONE AVAILABILITY (PATERSON, 1977)

Without Coal - Kepone Concentration Above Sediment (ppb)	With Coal - Kepone Concentration Above Sediment (ppb)	Duration	% Reduction
42	22	12 days	48%
44	19	4 days	57%
50	37	12 days	26%
63	40	1 day	36%

Based on Allied's promising results, batch adsorption tests were initiated at Battelle on a variety of coals. From the data in Table X.24, it can be seen that coals tested had less affinity for Kepone than Bailey Bay sediments. Consequently, these could not offer any protection to the system if added. This differs from conclusions drawn from Allied's work and is believed to be a function of contact time. The batch adsorption tests were shaken overnight. Allied's tests were run over a period of days. As noted earlier, the adsorption process on coal occurs very slowly. Consequently, the shaker results may reflect a failure to reach equilibrium or a difference in coal stocks.

It has been noted previously that activated carbon has been successfully applied in a contact facility to remove Kepone from solution. Hence, it stands as a viable option for elutriate treatment. The same is true for any of the sorbents found to be effective for in situ evaluations such as XAD-2 and ES863. Consequently, sorbents should be considered as candidates for both elutriate and in situ application. Similarly, activated carbon can be considered for application directly to the river without retrieval. This application would be in the same manner as the application of coal, but offers a higher degree of adsorption.

While in situ technology has not been employed in any large-scale applications, it is possible to estimate the likely costs involved from the work performed here. The assumptions and unit costs employed are outlined below:

In Situ Application of Retrievable Media -
- Dose Rate - 1.2 lb resins/ft^3 sediment
- Number of Applications = 2 (potential removal of 90% in highly contaminated sediments, greater in others)
- Resin Loss Rate = 25% of resin
- Cost of Resin = \$120/ft^3
- Unit Resin Loss Costs = 0.51/ft^3 sediment
- Application and Retrieval Cost = 0.10/ft^3 sediment
- Regeneration Costs = \$0.25/ft^3 sediment
- Disposal of Kepone Residuals = \$0.04/ft^3 sediment
- Total Unit Cost = \$0.90/ft^3 sediment

In Situ Application of Coal -
- Dose Rate = 1.2 lb/ft^3 sediment (This will reduce Kepone levels in water up to 80%)
- Cost of Coal = \$20/ton
- Unit Cost of Coal Applied - \$0.012/ft^3 sediment
- Unit Cost of Application = \$0.02/ft^3 sediment
- Total Unit Cost = \$0.032/ft^3 sediment

In Situ Application of Activated Carbon -

Dose Rate = 1 lb/ft^3 sediment
Cost of Carbon = $0.50/lb
Unit Cost of Carbon Applied = $0.50/ft^3 sediment
Unit Cost of Application = $0.02/ft^3 sediment
Total Unit Cost = $0.52/ft^3 sediment

No capital costs are offered at this time since conceptual designs have not been determined for key items in the process chain. Based on the above considerations, operational costs for these approaches are listed in Tables X.29 and X.30.

TABLE X.29. COMPARATIVE COST OF IMPLEMENTING IN SITU APPLICATION OF COAL AND RETRIEVABLE MEDIA OPTIONS IN VARIOUS KEPONE CONCENTRATION REGIMES ON THE JAMES RIVER

Kepone Concentration Regime (µg/g-ppm)	>10	1-10	0.1-0.99	0.02-0.09
Volume of Sediments - ft^3	6.8×10^6	6.8×10^7	3.0×10^9	3.6×10^9
Cost of In-Situ Application of Retrievable Media	6.1×10^6	6.1×10^7	2.7×10^9	3.2×10^9
Cost of Coal Application	2.9×10^5	2.9×10^5	9.7×10^7	1.2×10^8
Cost of Activated Carbon Applications	3.5×10^6	3.5×10^7	1.6×10^9	1.9×10^9

TABLE X.30. COMPARATIVE COST OF IMPLEMENTING IN SITU APPLICATION OF COAL AND RETRIEVABLE MEDIA OPTIONS IN VARIOUS REACHES OF THE JAMES RIVER

	Richmond to Jordan Point	Jordan Point to Jamestown Island	Jamestown Island to Newport News	Hampton Roads	Total
Volume of Sediments - ft^3	1.3×10^8	1.3×10^9	3.7×10^9	1.7×10^9	6.8×10^9
Cost of In Situ Application of Retrievable Media	1.2×10^8	1.2×10^9	3.3×10^9	1.5×10^9	6.1×10^9
Cost of Coal Application	4.3×10^6	4.3×10^7	1.2×10^8	5.4×10^7	2.2×10^8
Cost of Activated Carbon Applications	6.8×10^7	6.8×10^8	1.9×10^9	8.8×10^8	3.6×10^9

POLYMER FILMS

Use of nonretrievable sorbents constitutes a means of retarding or limiting Kepone availability. Alternately, this can be achieved by physically sealing or burying sediments. Such an approach utilizing polymer films has been tested on mercury-contaminated sediments (Widman and Epstein, 1972). Similar results have been obtained in Japan on PCB-contaminated sediments when in situ stabilization was conducted (Takenaka Komuten Co., 1976). An investigation was conducted to determine the feasibility of utilizing films to seal Kepone contaminated sediments in Bailey Bay.

In selecting a film for sealing bottom sediments, the following must be considered; major physical film properties of tear strength (200 to 300 lb); tensile strength (>3000 psi); water resistance (impervious to long-term total immersion); chemical resistance (specifically to Kepone or other contaminants found in the sediments); and temperature resistance (no embrittlement or softening over normal annual water temperature range). In addition, the thickness (weight) and the width of the film are considered important handling characteristics. The lightest film possessing the desired physical properties (possibly 1 to 2 mils) and a width of 6.1 m (20 ft) are desired.

All commercially available films were included in initial considerations for screening purposes. Many films were rejected from further consideration because they lacked one important property; for example, biaxially oriented polypropylene film possesses excellent tensile strength but poor tear strength. In general, most films were rejected because of size limitations (maximum width 72 in.). Raw material suppliers (pellets for casting film) were contacted for candidate processes. End-use suppliers such as nursery and agricultural product houses were rejected because of cost. However, a major supplier of polyethylene film was located who possessed the fabrication capability for 6.1 m (20 ft) wide film and who maintained sufficient inventory to be able to supply 3,340,000 m^2 (36,000,000 ft^2) in a reasonable time.

The film selected is 5 mm (2-mil) low density polyethylene. Rolls are 6.1 x 61 m (20 x 200 ft) with 7.6 cm (3 in.) core and a weight (4000 ft^2) of 17.3 kg (38 lb) manufactured by Poly Tech of Minneapolis, Minnesota.

Physical properties quoted for the 5-mm (2-mil) film are about 17000 kg/m^2 (3500 psi) tensile strength and 91 kg (200 lb) transverse and 136 kg (300 lb) machine tear strength. All other properties are also believed to be acceptable for the application.

The film laying system is conceived around a shallow draft film-laying barge. The film-laying barge traverses over the contaminated region of Bailey Bay and places a plastic film cover (which is then partially covered by gravel) over the bottom at the bay. The film-laying barge travels between the bay shore and a service barge which is anchored in the bay at the edge of the area to be coated with plastic film. The concept is illustrated in Figures X.6 through X.8.

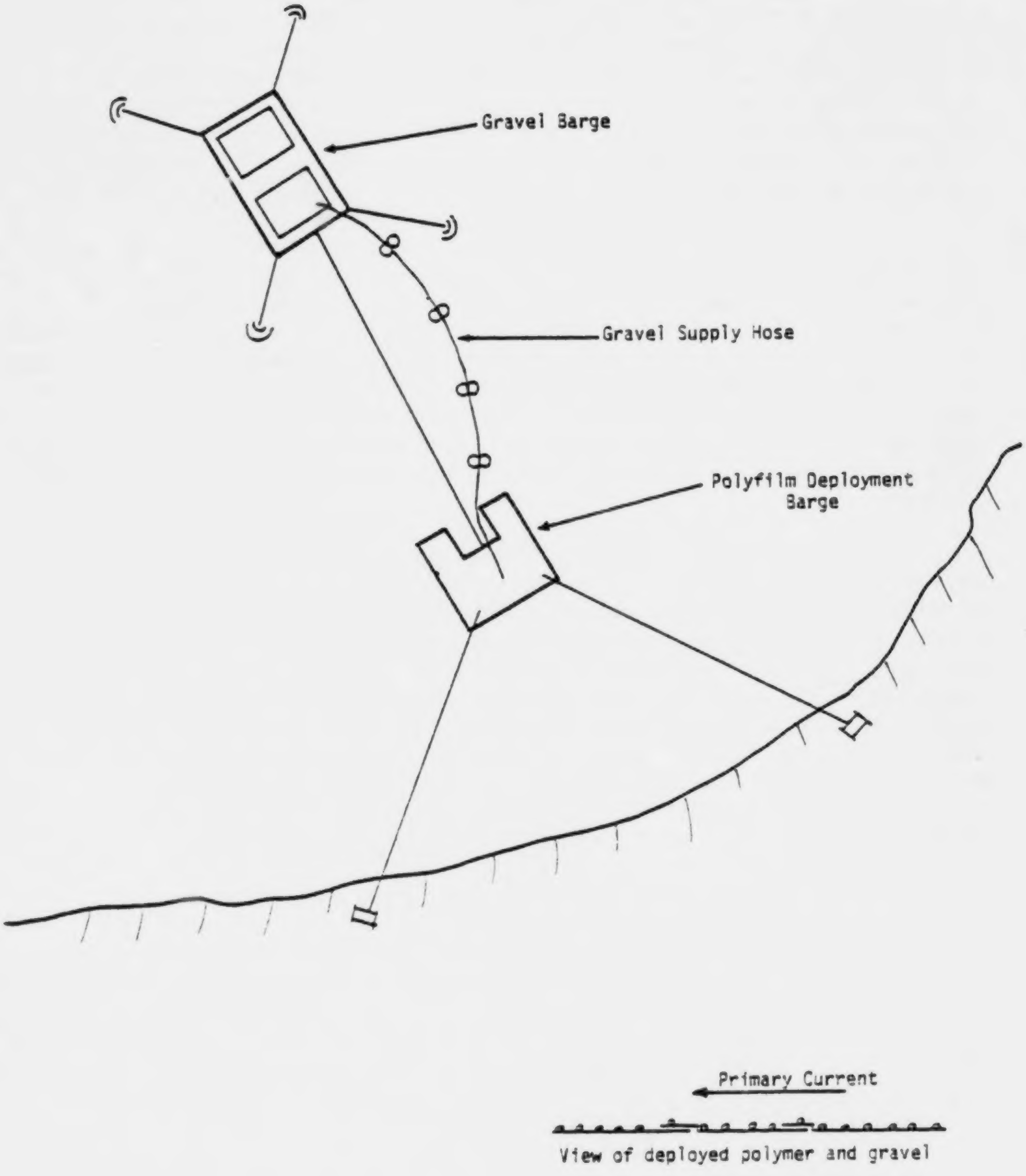
Gravel Barge
Gravel Supply Hose
Polyfilm Deployment Barge
Primary Current
View of deployed polymer and gravel

FIGURE X.6. Proposed Method of Deployment for Polymer Films

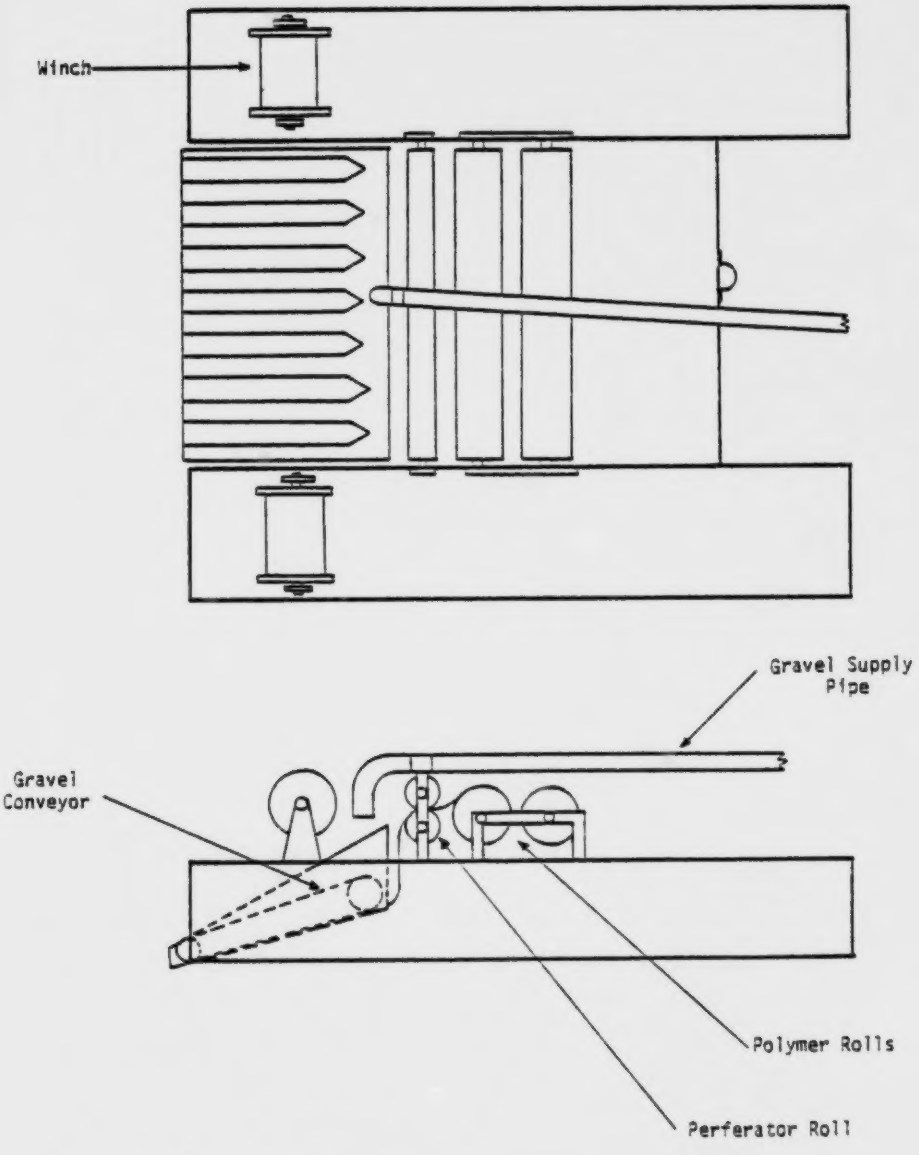
Winch
Gravel Supply Pipe
Gravel Conveyor
Polymer Rolls
Perferator Roll

FIGURE X.7. Conceptual Design of Apparatus for Deployment of Polymer Films

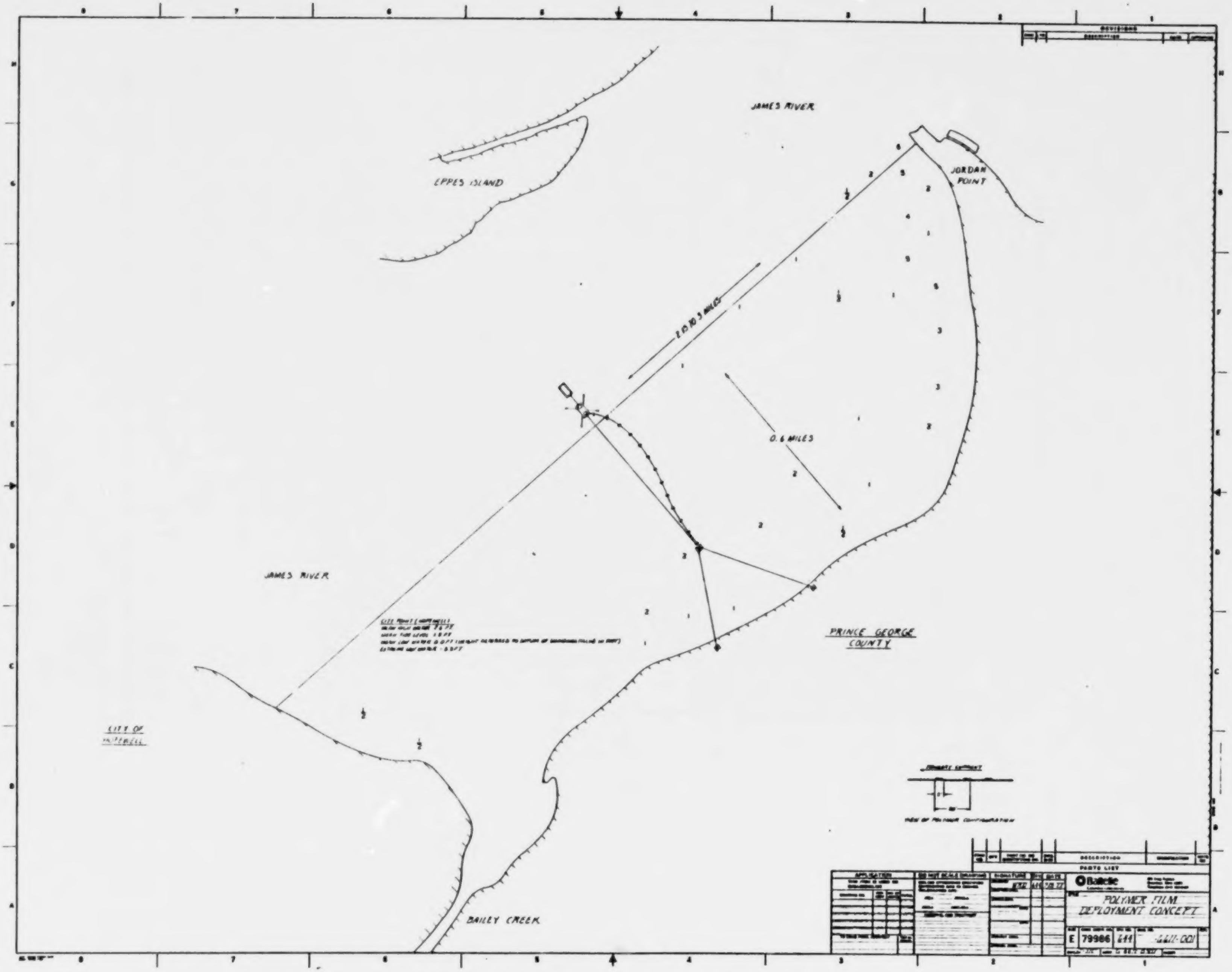
JAMES RIVER
EPPES ISLAND
JORDAN POINT
2.0 TO 3 MILES
0.6 MILES
JAMES RIVER
PRINCE GEORGE COUNTY
CITY OF HOPEWELL
BAILEY CREEK
VIEW OF POLYMER CONFIGURATION
REVISIONS
DESCRIPTION
PARTS LIST
Battelle
POLYMER FILM DEPLOYMENT CONCEPT
E
79986
611

FIGURE X.8. Overall Concept for ge-Deployment of Bottom-Sealing Film

Use of cohesive film covering requires perforation of the sheeting to allow for escape of gas produced in the anaerobic sediments, and addition of a ballasting material to hold the sheeting in place. Emplacement of the film requires clearing operations to remove bulk debris and either dredging of an access channel or stationing of support equipment in the margins of the navigational channel. Further details on film selection, equipment design, and operating and maintenance considerations can be found in Appendix F.

It must be noted that the polymer film is not a treatment technique in itself. It merely retards availability of the Kepone. This can be advantageous if natural degradation will subsequently reduce Kepone or if sedimentation covers the film over and essentially buries the contamination too deep to be available to aquatic communities. This will not be the case in Bailey Bay, however. Data indicate the degradation is not likely, and sedimentation would have to essentially fill the Bay before the Kepone would be rendered unavailable. Therefore, at best, the film will keep the sediments from continually supplying dissolved Kepone to the water column. There is reason to believe, however, that even this goal cannot be met. The need to perforate the sheeting for gas release will reduce the integrity of the seal. An upward flux of water through the sediments can continually bring dissolved Kepone and possibly contaminated small particulate matter through the film and thus contaminate the water column and new sediment above the seal. In light of these considerations, the value of applying the film to Bailey Bay is questionable.

The sediment-containment system described in this report can be developed and put into operation in Bailey Bay for a total cost of approximately $3,016,000, if channel-dredging is allowed; or for approximately $1,612,000, if channels are not dredged. The cost difference between the two approaches is the estimated cost of dredging and the costs for an additional slurry pump and extra slurry pipe if the nondredging approach is used. The costs associated with the two approaches are presented in Tables X.31 and X.32.

APPRAISAL

A summary of the processes and alternatives evaluated in this study is presented in Table X.33. In general, most alternatives were found to be ineffective or inappropriate for use in Bailey Bay and the James River. Several candidates, however, have shown promise and therefore merit further evaluation and comparative analysis with dredging options and an assessment of associated environmental impacts.

In limited laboratory studies, only two fixation agents were found to be effective for use on spoils: molten sulfur and Por Rok Epoxy Grout. The Dowell M179 displayed good resistance to leaching, but is sensitive to crushing or stresses which would break the surface film. Consequently, it is deemed more appropriate for percolation control (ground sealing) than spoils fixation. Considerations pertinent to selection between the molten sulfur and Epoxy Grout are summarized in Table X.34.

TABLE X.31. FIRST APPROACH POLYMER FILM SEALANT - PRELIMINARY COST ESTIMATE
BAILEY BAY

	Rate	Amount or Time	Cost
Site Preparation			
Labor to Clear Shoreline	$5/yd^2	10 ft x 20,000 ft/(9 ft^2/yd^2)	$ 111,100
Dredging	$2.95/yd^3	500,000 yd^3 mud	1,475,000
			$
Service Barge			
Barge	$300/day	6 months x 30 day/mo	$ 54,000
Crane	$70/hr	6 months x 172 hr/mo	72,200
Pump	1	Installation	20,000
Hose	3500 ft	$317/22 ft	50,400
Labor	$20/hr	6 months x 160 hr/mo x 5 men	96,000
			$
Gravel Barges			
3 Gravel Barges	$300/day	6 months x 30 day/mo x 3 barges	$ 162,000
Tug Service	$350/day	6 months x 30 day/mo	63,000
			$ 225,000
Film Barge			
Film Barge Less Retracting Winches			$ 100,000
Retracting Winches and Laser			55,000
Labor	$20/hr	6 months x 20 day/mo x 8 hr/day x 4 men	76,800
			$ 231,800
Consumables			
Film	$4.50/100	$4.50/1000 ft^2 x 36,000,000 ft^2 x 20/17	$ 190,600
Gravel	$3.00/ton	163,350 tons	490,000
			$ 680,600
		TOTAL COST	$3,016,140

TABLE X.32. SECOND APPROACH POLYMER FILM SEALANT - PRELIMINARY COST ESTIMATE BAILEY BAY

	Rate	Amount or Time	Cost
Site Preparation			
Labor to Clear Shoreline	$\$5/yd^2$	$10\ ft \times 20{,}000\ ft/(9\ ft^2/yd^2)$	$ 111,100
			$ 111,100
Service Barge			
Barge	$300/day	6 months x 30 day/mo	$ 54,000
Crane	$70/hr	6 months x 172 hr/mo	72,200
Pump	2	Installation	40,000
Hose	7000 ft	$317/22 ft	100,800
Labor	$20/hr	6 months x 160 hr/mo x 5 men	96,000
			$ 363,000
Gravel Barges			
3 Gravel Barges	$300/day	6 months x 30 day/mo x 3 barges	$ 162,000
Tug Service	$350/day	6 months x 30 day/mo	63,000
			$ 225,000
Film Barge			
Film Barge Less Retracting Winches			$ 100,000
Retracting Winches and Laser			55,000
Labor	$20/hr	6 months x 20 day/mo x 8 hr/day x 4 men	76,800
			$ 231,800
Consumables			
Film	$4.50/100	$\$4.50/1000\ ft^2 \times 36{,}000{,}000\ ft^2 \times 20/17$	$ 190,600
Gravel	$3.00/ton	163,350 tons	490,000
			$ 680,600
		TOTAL COST	$1,611,500

TABLE X.33. SUMMARY OF RESULTS FOR CANDIDATE ALTERNATIVES IN BAILEY BAY AND THE JAMES RIVER

Approach	Alternative	Results	Comments
Spoil Fixation	Silicate Bases	High pH solubilizes Kepone	Ineffective
	Gypsum Bases	Physically breakdown with immersion	Ineffective
	Organic Bases - Epoxy	Yields 10-fold reduction in Kepone levels,	Effective
	- Dowell	Resist leaching, poor response to elutriate test	Effective for percolation control
	Sulfur Bases - Molten Sulfur	Yields 10-fold reduction in Kepone leachate levels	Effective
	- Sulfaset	Intermediate between silicate base and sulfur	
	Asphalt	Difficult to apply to wet sediments	Inappropriate
Elutriate or Ex Situ Treatment	Biological Degradation	Promising strains of fungi and mold	Not sufficiently developed
	Land farming	No degradation, photo or biological	Ineffective
	Amine photosensitization	Degradation occurs at exposed surfaces	Inappropriate potential for use on surface soils
	Chlorine Dioxide	No degradation	Ineffective
	Ozonation	No degradation	Ineffective
	Ultrox (Westgate) Ozone and UV	Good decomposition	Effective for Solutions
	γ Radiation	Dechlorinates, by-products unidentified	Requires further testing
	Electron Beam Radiation	Can infer from PCB work only	Requires direct testing
	Catalytic Reduction	No apparent degradation	Ineffective
	Adsorption	Carbon and synthetic resins	Effective
	Coagulation	Removes particulate Kepone	Effective for bulk reduction
In Situ Processes	Retrievable Sorbents	Specific sorbents capable of removal	Effective
	Coal	Initial data suggests no advantages	Requires further study
	Polymer Films	Holding action only, need to perforate, may render ineffective	Inappropriate
	Activated Carbon	Intermediate between coal and retrievable sorbents	Effective

TABLE X.34. COMPARISON OF SELECTED FIXATION AGENTS

Agent	Unit Cost, $/ft^3 fixed	Availability	Effectiveness	Requirements
Molten Sulfur	$1.30	Readily Available	Good	≥50% Solids
Epoxy Grout	$12.50	May Be Production Limited	Slightly More Consistent	≥50% Solids

Based on the considerations in Table X.34 molten sulfur is the preferred alternative for stabilizing dredge spoils. At the same time it is recognized that there may be environmental impacts associated with dredged spoils fixation.

Management alternatives resulting in the placement of dredge spoils containing high concentration of Kepone require consideration of the short- and long-term effects as well as local and distance effects. These considerations apply whether the spoils are placed on land above sea level, as underwater dikes, or at intertidal sites.

Elemental sulfur is stable in water but readily changes to soluble and potentially toxic forms when mixed with reducing as well as oxidizing sediments. Molecular compounds of concern include hydrogen sulfide and sulfur dioxide; these should be handled carefully.

Gaseous forms such as hydrogen sulfides can cause significant odor problems in the surrounding area. Gases in high enough concentrations can be toxic to humans, animals and plants. Soluble aqueous forms can contaminate surface and ground water with significant impact on water quality and biota. Consequently, application of this alternative would require that treated dredge spoils be located topographically and physiographically to minimize impacts to air and water quality.

Sulfur content in a radio of 1:1 sulfur to sediments would require consideration of additional treatments. Particularly that of spoil surface protection from precipitation and the establishment of a sealed bottom pad to prevent sulfur compound leachates from contaminated ground and surface waters. Surface sealing would minimize atmospheric suspension. The isolation of terrestrial treated spoils can be effectively accomplished by application of readily available sealants.

Treatment of spoils in intertidal areas which are intermittently exposed to air and water could have serious effects on all aquatic forms within several kilometers depending on currents and eddy pools. The application of this treatment to intertidal spoils is probably the least desirable of the placed spoils alternatives, primarily due to leachate distribution control.

Treatment of submersed spoils should be expected to have a much reduced impact on health and environmental quality because of reduced oxidation potential. Prior to the application of sulfur to submersed spoils, more information is needed pertaining to degradation products and their solubility in James River waters over a range of salinities. Further consideration would need to be given to the erosion of submerged spoils and the possible implications to water quality and biota as controlled by tidal waves and downstream flow.

The application of sulfur to any of the spoil placement locations would require intensive monitoring on a short-term basis in order to assess monitoring requirements in the long term as well assess possible undesirable long-term environmental effects.

It is judged that this treatment method could be quite effective on the condition that the redistribution of treatment chemicals be minimized by application of mitigative measures.

Of the elutriate and/or slurry treatment processes, two were judged effective; two require further testing before an appraisal can be made; and one may be attractive for specific applications. The alternatives deemed effective, the adsorption and the Westgate Ultrox processes, can be applied to solutions of dissolved Kepone. Both would require clarification/filtration for slurries or turbid waters before they could be effectively applied. (High solids content that could be tolerated for adsorption of powdered carbon were employed in place of a granular media, but recovery of the carbon would be difficult in the presence of the other solids.) Coagulation would be effective for clarification of waste streams where the removal of contaminated particulates is sufficient. Disposal of residuals would still be required.

Destruction with γ radiation or electron beam radiation cannot be ruled out. Preliminary tests indicate dechlorination, at a minimum, with γ radiation; and tests with electron beam radiation of polychlorinated biphenyls show promise. In order to fairly evaluate these options, it will be necessary to perform empirical studies using Kepone. In the case of γ radiation, thin film exposure should be evaluated to determine necessary doses and the nature of by-products. Until these data are available, irradiation options cannot be properly evaluated. Considerations pertinent to the three effective means of elutriate treatment are provided in Table X.35.

Based on the considerations given above, the ozone-UV process is deemed best suited to elutriate treatment. Costs projected here will be appropriate for application to relatively clear waters. If pretreatment is required as would be the case for elutriate from dredging, capital costs must be increased by $14.1 million for a 50 MGD plant and operating costs increased an additional $0.77/1000 gallons treated.

TABLE X.35. COMPARISON OF SELECTED ELUTRIATE TREATMENT ALTERNATIVES FOR A 50 MGD OPERATION

Process	Unit Cost Without Amortization, $/1000 gal treated	Capital Cost, $ millions	Limitations
Ultrox (Ozone, UV)	0.074	7.9	Turbid waters require pretreatment.
Carbon Adsorption	0.048	29.1	Turbid waters require pretreatment. Regeneration system may require modification to ensure destruction of Kepone.
Coagulation	0.055	10.1	Will remove only Kepone associated with particulate matter.

No major environmental impacts are anticipated with the application of the ozone-UV treatment process other than those associated with construction of the facilities and the increased demand for power. However, no work has been performed to date to determine the presence of degradation products or their toxicity.

Of the in situ approaches considered, all show some degree of effectiveness. The polymer film is considered inappropriate, however, since it offers little more than a delay in implementing an actual removal and/or destruction alternative. The retrievable sorbents were found effective. The use of coal remains in question. While Allied Chemical Corporation reported a reduction in Kepone levels in the water column, adsorption tests and various coal samples at Battelle revealed partition characteristics essentially the same as those for natural sediments. It must be determined if this reflects differences in the coal samples, or artifacts in one of the experimental designs. The assessment of the use of coal as an alternative will be incomplete until that question is resolved. Activated carbon on the other hand will definitely retard availability. A comparison between the characteristics of in situ alternatives is given in Table X.36. Based on considerations of that comparison, activated carbon application is selected as the best in situ alternative unless subsequent data demonstrate the effectiveness of coal. In that event, coal would be the alternative of choice in all areas but those contaminated at ≥ 1 μg/g (ppm) Kepone where retrievable media should be employed. The exception is made to reflect the fact that at high sediment Kepone concentrations, the potential reduction in availability with coal or activated carbon would still allow unacceptable levels of Kepone in water.

TABLE X.36. COMPARISON OF IN SITU ALTERNATIVES

Alternatives	Unit Cost, $\$/ft^3$	Limitations
Retrievable Media	0.90	Requires incineration of regenerate and production of media not currently commercially available.
Application of Coal	0.032	Requires further proof of efficiency.
Application of Activated Carbon	0.52	Will retard availability but not remove Kepone.
Polymer Film	0.044	Applicable only to embayments such as Bailey Bay.

Technology has been developed in Japan for in situ stabilization of sediments with formulations produced by Takenaka (TJK, Inc.). Should these formulations prove effective, in situ stabilization would also be a viable option. All in situ approaches will require more testing and field evaluation as well as a detailed assessment of potential impacts on benthic organisms. Further information on this work can be found in the EPA report on the Kepone Mitigation Feasibility Project.

Environmental impacts associated with in situ treatment are not well understood. However, it is clear that these must be considered. A discussion of the implications of applying coal and retrievable sorbents follows.

Coal. The effects of the coal deposition alternative have both physical and chemical ramifications to the James River ecosystem.

Initially, the finest coal particles will be suspended in the water. These suspended solids reduce light penetration, which inhibits algal primary productivity by restricting photosynthesis. The particles can also directly affect fish and gill-breathing macroinvertebrates by clogging or causing abrasion of the gills.

Longer term impacts will be caused by the layer of coal covering the sediments. Normally, the aquatic microorganisms in the sediments breakdown the organic and inorganic material into compounds or nutrients that are circulated by tidal action and currents. These decomposition products are the base for aquatic food chains. The nutrients are required by algae and larger aquatic plants, while the organic compounds are consumed by zooplankton, clams, and snails. All of the above organisms provide a food source for carnivores at the top of the food chain, such as fish. When these organisms die, they fall to the sediments and the decomposition process begins again. Thus, the sediments are the site of nutrient cycling and retention.

The layer of coal placed over the sediments would cover existing organisms in the sediments, making these benthic organisms unavailable as a food source to fish. The microscopic decomposers in the sediments, however, would continue to anaerobically break down the sediments. Circulation of decomposed material might be slowed, but turnover will eventually stir the coal particles into the sediments.

Chemical changes due to the formation of acid by the pyrite in coal may result in a negative impact on aquatic biota. This effect would be relatively local due to the immense buffering capacity of the James River water.

The sulfuric acid created from the pyrite in coal can produce many other water pollutants by secondary reactions with minerals and organic compounds in coal or water. These pollutants include iron, aluminum, manganese, and toxic trace elements. A few of the toxic trace elements analyzed in effluents from Pennsylvania anthracite coal refuse include nickel, copper, and zinc. The pH of the effluent streams analyzed was as low as 3.0 (Martin, 1974). Since the pH effects are likely to be local, solubilized minerals will quickly precipitate as they migrate outward.

Acid formation depends on oxygen for oxidation of the pyrites. In areas such as Bailey Bay which have been receiving sizable discharges of organic material and nutrients from industrial outfalls and municipal sewage discharges, little acid formation would occur in the first place.

Retrievable Sorbents. The retrievable sorbents found to be effective in removing Kepone are quite uniform in size and inert to most biochemical systems operable in the environment. Consequently, little effect is anticipated for downriver redistribution of fines or release of toxic materials.

Retrieval of the sorbent would be expected to have some impact on water quality as a result of some bottom scouring and possible desorption of compounds, some of which may affect water quality for a short period.

It is assumed here that the spent retrievable medium would be recovered in part and that the possible impacts of the unrecovered sorbent medium would require further study to determine its fate and impact to water quality and biota. However, the inert nature of the media suggests minimal effects.

General Considerations for In Situ Treatments. There are several aspects of in situ treatment needing further analyses. The most important of these have to do with the effect of the hydrodynamics of the James River and its features in relation to the stability, integrity, and behavior of emplaced materials as well as obvious concern over the fate of benthic life after addition of large quantities of materials to the sediments.

The coal adsorbent, depending on density, size, and particle statistics, may undergo significant redistribution and stratification in time. This effect may or may not have a significant impact on the effectiveness of the treatment.

The retrievable solid is assumed to have a higher density than that of 1.3 assumed for coal. Its placement may have a significant effect through sediment gradation and possible channel armoring. Should channel armoring occur in localized areas, there would be an effect on bed load movement and distribution of fines. Furthermore, size-density could affect rates of redistribution as well as settling and entrapment of the medium in the sediments.

Another important aspect concerns the movement dynamics of interstitial water in the sediments. Upwelling due to variable rates of aquifer discharge could have a significant effect on the behavior of treatment types. Sediment to water flow where coal and/or the retrievable solute might be placed could increase the sorption efficiency. Downward migration of water would do the reverse, reducing the effectiveness of coal and retrievable sorbent because Kepone would be desorbed; solubilized Kepone would show some movement down through the sediments.

The stability of coal particles in the fresh-water-salt wedge interface poses additional concerns. As it is not possible to accurately predict the location or migration of the salt wedge in time, the effect may have significant impact on the downstream movement of contaminated coal. Optimally, the coal should remain relatively localized for several years. A downstream flush of contaminated coal could have severe effects on water quality and biota not now exposed to high concentrations of Kepone.

It should be noted that these special considerations may not, in fact, reduce the desirability for implementation of a particular treatment type but they may affect method and location of treatment application.

A study of dredging technology was performed by the Norfolk District, U.S. Corps of Engineers as a part of the overall EPA Kepone Mitigation Feasibility Project. (See "Capturing, Stabilizing, or Removing Kepone in Bailey Bay, Bailey Creek, and Gravelly Run," 1978.) Data from that work are employed here to assist in the evaluation of alternative costs associated with mitigation options. All dredging is assumed to use the oozer technology recommended by the Corps of Engineers.

The cost of employing the oozer dredge and associated spoils disposal alternatives are compared to those for use of retrievable sorbents and coal in Table X.37. Costs are based on the unit costs developed in this report as well as the following:

Oozer pump dredge - produces spoils at 50% solids unit cost is $\$2.95/yd^3$ - $\$0.11/ft^3$ (Corps of Engineers, 1978)

Ocean disposal* - unit cost are $\$0.49/ft^3$ for 50% solids

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* D. D. Smith and R. P. Brown, "Ocean Disposal of Barge-Delivered Liquid and Solid Wastes from U.S. Coastal Cities," (Pillingham Corp., La Jolla, CA) Contract No. PH 86-68-203, U.S. EPA 1971. This document cites high rate values for Atlantic Coast disposal based on the assumption that wastes must be dispersed of off the continental shelf. If lesser distances are approved, the cost may be reduced by a factor of 8.

Incineration - unit cost if \$1.50/ft^3 for 50% solids

Stabilization - spoils can be stabilized directly if available at 50% solids

TABLE X.37. COMPARISON OF COSTS FOR IMPLEMENTATION OF ALTERNATIVES TO THE JAMES RIVER (\$)

Alternative	Turkey Island to Jordan Point	Jordan Point to Jamestown Island	Jamestown Island to Newport News	Hampton Roads	Total
Percentage of Kepone Residuals, %	12.8	14.5	70.9	1.8	100
Oozer-Dredge with Ocean Disposal	1.5×10^8	1.6×10^9	4.2×10^9	1.9×10^9	7.7×10^9
With Molten Sulfur Stabilization(a)	1.9×10^8	2.0×10^9	5.3×10^9	2.4×10^9	9.8×10^9
With Incineration	2.1×10^8	2.3×10^9	6.0×10^9	2.8×10^9	1.1×10^{10}
In-situ Application of Retrievable Solvents	1.2×10^8	1.3×10^9	3.3×10^9	1.5×10^9	6.2×10^9
Application of Coal	4.2×10^6	4.5×10^7	1.2×10^8	5.4×10^7	2.2×10^8
Application of Activated Carbon	6.8×10^7	7.3×10^8	1.9×10^9	8.8×10^8	3.6×10^9

(a) Does not include land acquisition for the final repository.

From the data, it is clear that the cost of disposal of dredge spoils overrides the cost of dredging and puts even these alternatives into a very costly category. Only the application of coal can be undertaken for less than a half a billion dollars if the entire river is to be treated. If the less concentrated sediments near Hampton Roads are not addressed, 25% reduction in costs can be achieved. However, costs for application of coal would still exceed \$100,000,000, and coal has yet to be proven as effective. The next closest alternative, application of activated carbon should cost over three billion dollars. On a unit cost basis, the alternatives in ascending order of costs are:

Application of Coal - \$0.03/ft^3
Application of Activated Carbon - \$0.52/ft^3 sediment
Retrievable Sorbents in situ - \$0.90/ft^3 sediment
Oozer with Ocean Disposal - \$1.11/ft^3 sediment
Oozer with Molten Sulfur Stabilization - \$1.41/ft^3 sediment
Oozer with Incineration - \$1.61/ft^3 sediment

While costs are high, the relative cost of retrievable media compared to dredge and disposal options is of interest. This will be true for cases where low contaminant levels persist and especially where the need to remove contaminants dictates against application of nonretrievable agents. Other options such as in situ stabilization which may be considered feasible after further evaluation, should be costed and compared with these data when those evaluations are complete.

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APPENDICES

APPENDIX A

THEORETICAL CONSTRUCTS TO DETERMINE SORPTION AND VOLATILITY PROPERTIES OF KEPONE

APPENDIX A-1

THEORETICAL DEVELOPMENT OF SORPTION-DESORPTION CONSTANTS FOR KEPONE ON SEDIMENTS

(Contents consist of reports by S. Pavlou, URS Company
consultant on sorption-desorption mechanisms.)

This report is a summary of the series of computations which provide an estimate of the partitioning of Kepone between suspended particulate matter and water in the James River. Due to the paucity of data on the physical chemical properties of Kepone (a rather intensive survey of the literature from 1950 to date produced no relevant information), the theoretical calculations by necessity rely on crude estimates of various physical chemical parameters. Whenever possible, these approximations have been obtained by comparing the partitioning behavior of chemically similar compounds and by considering additivity principles within homologous series.

From the limited data available it appears that Kepone is not a "well behaved" molecule in terms of its solubility and liquid-liquid partition coefficients. These parameters depend on the chemical characteristics of the aquatic system in question. For example, the solubility shows a very strong dependence on pH with a pronounced discontinuity at high pH values (Meiggs, 1976). It should be pointed out here that, due to the small number of measurements, the reliability of the data is uncertain. Nevertheless, the available data was used for conditions which approximate normal riverine systems, i.e., for a pH range between 7 and 8, a temperature of 20°C and water of low ionic strength.

The preliminary theoretical calculations are based on the application of a simple BET-isotherm equation assuming that 1) only London dispersive and hydrophobic interactions constitute the primary forces controlling the distribution of Kepone between aqueous and suspended phases, and 2) the system is equilibrated at low aqueous concentrations (<10% saturation). Although a detailed discussion of the approach has been presented elsewhere (Dexter, 1976; Pavlou and Dexter, 1977; Dexter and Pavlou, 1977), a brief review of the fundamental definitions is presented below.

The general form of the component concentration ratio K can be expressed as

$$K \equiv \frac{C_{y(s)}}{C_{y(w)}} = \frac{A_s^* M_y}{\bar{A}_y C^0_{y(w)}} \exp[(E_s - E_m)/RT] \qquad \text{(A-1)}$$

where A_s^* is the specific surface area of the ambient suspended particulate matter (SPM), M_y is molecular weight of the adsorbate ($cm^2 mol^{-1}$), and $C^o_{y(w)}$ refers to the solubility of the adsorbate ($g\ g^{-1}$). $C_{y(s)}$ and $C_{y(w)}$ correspond to the concentration of adsorbate on SPM and in solution ($g\ g^{-1}$), respectively. E_s is the energy of interaction of Y with the bare surface (formation of the first adsorption layer) and E_m is the energy of interaction of Y with covered surface (formation of multilayers); both quantities are in units of cal mol^{-1}. R refers to the gas constant (cal deg^{-1} mol^{-1}) and T to the temperature (deg). These parameters were evaluated as follows:

M_y and $C^o_Y(w)$. These quantities are the literature values. M_y equals 491 g mol^{-1} and $C^o_Y(w)$ equals 0.3×10^{-6} g cm^{-3}. The solubility value was obtained from EPA's data (Meiggs, 1976) at 25°C in tap water and pH of 7.2.

$\bar{A}_y$. This quantity was calculated from the appropriate molecular geometry using tabulated data. A value of 1.61×10^9 cm^2 mol^{-1} was obtained.

A_s^* and T. Due to the absence of suspended load and particle size data, the specific surface for SPM in the James River was estimated to a first approximation by using the value of 5×10^5 $cm^2 g^{-1}$ measured in Puget Sound. A value of 20°C was considered a reasonable representation of the mean temperature regime in the James River.

E_s and E_m. The energetic terms were computed from adsorption free energies which in turn were obtained from interfacial free energies as previously described (Pavlou and Dexter, 1977). Therefore, the energy term in the exponential of equation (A-1) can be expressed as

$$E_s - E_m = \bar{A}_y[\sigma_{sw} - \sigma_{sy} - \sigma_{yw}] \tag{A-2}$$

where σ refers to the interfacial tension with the subscripts sw, sy, and yw denoting the SPM/water, SPM/adsorbate and adsorbate/water interfaces, respectively. The values for the interfacial tensions were calculated from surface tensions based on the data and methods of Fowkes (1964). The following aspects were considered in obtaining these quantities.

Surface Tension of Water (σ_w). The surface tension of pure water is extensively documented; a value of 73 ergs cm^{-2} was used in these calculations. A substantial fraction of this energy, about 22 ergs cm^{-2} (= σ_w^d), is accounted for by London dispersive forces, while the remainder results from hydrogen bonding.

Surface Tension of the Solid Matrix (σ_s). Previous discussions (Dexter, 1976; Dexter and Pavlou, 1977) have shown that most aquatic particulate matter is covered by at least a thin film of a relatively polar organic matrix, comprised predominantly of fulvic and/or humic acid residues. Due to the molecular configuration of the predominant moieties of these compounds, the surface activity of this film should not differ substantially in magnitude from that of a short chain alcohol, e.g., propanol. Therefore, the surface tension of the adsorbing matrix, σ_s, was taken as 24 ergs cm^{-2} with σ_s^d (the dispersive interaction) providing the major contribution (22 ergs cm^{-2}) to this value.

Surface Tension of Kepone (σ_y). The surface tension of Kepone has not been directly measured, but was generated from additivity considerations based on the behavior or similar organic compounds. Table A.1 lists the surface tensions of a homologous series of alkyl hydrocarbons. The unsubstituted molecules show a fairly regular increase in σ_y with increasing carbon number. Monochloro substitution results in increased values of σ_y due to greater polarity, but the relative increase from the unsubstituted parent molecule is less with longer carbon chains. Dichloro substitution again increased the σ_y values, but in this case virtually all differences within the homologous series are eliminated. Similarly, the highly chlorinated Kepone precurser, perchlorocyclopentadiene, has a σ_y nearly identical with those of the more highly substituted n-paraffins. A chlorinated Kepone analog, (Mirex) would thus have a similar predicted surface tension $\sigma_{k(Cl)} = 38$ ergs cm^{-2}.

Kepone also has a ketone oxygen. Table A.2 lists surface tension values for a homologous series of cyclic ketones. The incremental increase in σ_y associated with the carbonyl group ($\geq c = 0$) is of interest here. As was the case with Cl substitution, addition of the carbon-oxygen double bond reduces the carbon chain effect, but there is also less variation of σy with increasing numbers of carbons within the same cyclic series. Therefore, for higher molecular weight cyclic compounds, the increase in σ_y due to the presence of the carbonyl group is only about 7 ergs cm^{-2}. The surface tension of Kepone can then be approximated as the sum of the effects of chlorine and the $\geq c = 0$, i.e., $\sigma_k \simeq 38 + 7 = 45$ ergs cm^{-2}. From analogy with other polar organic compounds, the majority of this force is London dispersive ($\sigma_k^d \simeq 40$ ergs cm^{-2}).

Calculation of Interfacial Tensions. Relatively few interfacial tension measurements are available in the literature. However, the technique presented by Fowkes (1964) can be used to estimate the London dispersive contribution, while polar interactions can be accounted for by additivity considerations from comparisons with similar organic moieties. The basic equation is simply

$$\sigma_{sl} = \sigma_s + \sigma_l - 2\sqrt{\sigma_s^d \sigma_l^d} - \sigma_{sl}^H \tag{A-3}$$

where σ_{sl} is the interfacial tension between surface, s, and liquid, l; σ_s, σ_l, σ_s^d and σ_l^d were defined earlier and σ_{sl}^H represents the polar (hydrogen bonding) interaction. An identical equation describes liquid-liquid interfacial tension. The pertinent values of σ_s, σ_s^d, σ_w, σ_w^d, σ_k, and σ_k^d were those described earlier.

Values of σ_{sw}^H and σ_{kw}^H were estimated as shown in Table A.3 by measured interfacial tensions between water and a number of simple polar organic compounds (column 1) and the corresponding σ_{lw} values calculated if only London dispersive interactions were operating (column 2). The difference

TABLE A.1. REPRESENTATIVE SURFACE TENSIONS AT 20°C USED TO ESTIMATE THE DEPENDENCE OF σ FOR KEPONE ON DEGREE OF CHLORINATION[a,b]

Compound	n-paraffin	1-chloro	1,n-dichloro	multichloro
A. Pentane	16.05	24.94	35.75	
hexane	18.04	26.94	35.99	
heptane	20.14	27.02	36.03	
octane	21.62	27.72	36.11	
nonane	22.85	28.34	36.51	
B. perchlorocyclopentadiene				37.50

---

[a] Jasper, 1972

[b] Values are in units of ergs cm^{-2}

TABLE A.2. REPRESENTATIVE SURFACE TENSIONS AT 20°C USED TO ESTIMATE THE DEPENDENCE OF σ FOR KEPONE ON THE KETONE GROUP[a,b]

Compound	n-cyclo	1-keto
cyclopentane	23.34	33.35
cyclohexane	26.43	35.19
cycloheptane		34.66
trans-hexahydro-2-indane		35.03

---

[a] Jasper, 1972

[b] Values are in units of ergs cm^{-2}

TABLE A.3. REPRESENTATIVE WATER-ORGANIC INTERFACIAL TENSION AT 20°C USED TO ESTIMATE σ_{sw}^{H} [a,b]

Compound	σ_{sw}	σ_{sw}^{d}	σ_{sw}^{H}
aniline	5.8	53.7	47.9
di-n-butylamine	10.3	51.0	40.7
octanoic acid	8.5	51.3	42.8
cyclohexanol	3.9	51.9	48.0

---

[a] Fowkes, 1964

[b] Values are in units of ergs cm^{-2}

between these values represents the decrease in interfacial tension resulting from polar interactions, σ_{1w}^{H} (column 3). For all of the compounds, σ_{1w}^{H} (= σ_{sw}^{H}) is quite invariant and averages about 43 ergs cm^{-2}. For sterically hindered polar groups as found in Kepone, the corresponding value should be lower. Therefore, a value of 35 ergs cm^{-2} for σ_{kw}^{H} was considered a reasonable estimate.

No direct data is available for σ_{sk}^{H}, which in this case represents the polar interaction between similar organic compounds. However, Table A.4 compares the strength of σ^{H} for water on a number of polar surfaces (metal oxides) with the corresponding σ^{H} for propanol, a representative polar organic compound (column 1). A comparison of the relative strengths of the interactions (column 2) indicates that σ^{H} for propanol is about 20% of the corresponding σ_{ws}^{H}. Applying this value to the σ_{sw}^{H} obtained from Table A.3 yields a value of $\sigma_{sk}^{H} \simeq 9$ ergs cm^{-2} (= 0.2 x 43). The required set of interfacial tensions were then calculated, based on two different assumptions:

1) the polar interactions are applicable to all interfacial tensions, yielding the set of values presented in Table A.5.

2) assuming the polar carbonyl group of Kepone would only be oriented in one direction relative to the solid-Kepone-water interface, the lowest net interfacial tension would require an orientation yielding the highest σ^{H} value. This would occur when the Kepone molecule has the carbonyl group facing away from the solid matrix ($\sigma_{kw}^{H} > \sigma_{sk}^{H}$). Under these conditions, σ_{sk}^{H} would not be applicable, and a different set of interfacial tensions can be calculated (Table A.6).

Based on these data and using Equation (A-2), two values for the adsorption energy terms were calculated:

Case 1. $E_s - E_m = 1.61 \times 10^{9}\ (2 - 1 - 24)$ ergs mol^{-1}

$= -3.70 \times 10^{10}$ ergs mol^{-1}

$= -8.85 \times 10^{2}$ cal mol^{-1}

Case 2. $E_s - E_m = 1.61 \times 10^{9}\ (2 - 10 - 24)$ ergs mol^{-1}

$= -5.15 \times 10^{10}$ ergs mol^{-1}

$= -1.23 \times 10^{3}$ cal mol^{-1}

Subsequent to incorporation of these terms in Equation (A-1), two values for the distribution ratios were obtained. These vary by the differences in the predicted adsorption energies,

Case 1. $K = 1.05 \times 10^{5}$

Case 2. $K = 5.69 \times 10^{4}$

TABLE A.4. COMPARISON OF σ^H_{sw} and σ^H_{sp} (SURFACE-PROPANOL) FOR SOME SOLID SURFACES [a,b]

Surface	σ^H_{sw}	σ^H_{sp}	$\sigma^H_{sp}/\sigma^H_{sw}$
anatase	344	56	0.16
silica	368	84	0.23
barium sulfate	362	96	0.26
stannous oxide	336	54	0.16

---

[a] Fowkes, 1964

[b] Values are in units of ergs cm^{-2}

TABLE A.5. INTERFACIAL TENSION CALCULATIONS (CASE 1)

a) $$\sigma_{sw} = \sigma_s + \sigma_w - 2\sqrt{\sigma^d_s \ \sigma^d_w} - \sigma^H_{sw}$$

$$= 24 + 73 - 2\sqrt{22 - 22} - 43$$

$$= 2 \text{ ergs cm}^{-2}$$

b) $$\sigma_{sk} = \sigma_s + \sigma_k - 2\sqrt{\sigma^d_s \ \sigma^d_k} - \sigma^H_{sk}$$

$$= 24 + 45 - 2\sqrt{22 - 40} - 9$$

$$= 1 \text{ erg cm}^{-2}$$

c) $$\sigma_{kw} = \sigma_k + \sigma_w - 2\sqrt{\sigma^d_k \ \sigma^d_w} - \sigma^H_{kw}$$

$$= 45 + 73 - 2\sqrt{40 - 22} - 35$$

$$= 24 \text{ ergs cm}^{-2}$$

The first value appears to be more reasonable since it recognizes the probable preferred surface orientation of the Kepone molecules. It is interesting to note that, even though Kepone is considerably more soluble than the chlorobiphenyl (CB), the predicted K value is very similar to that determined in previous work (Dexter, 1976; Dexter and Pavlou, 1977). It must be remembered that the adsorption results from the balance of three basic interactions: water-surface, surface-Kepone, and water-Kepone. In this case, while the attractive forces between Kepone and water are greater than for the PCB (as evidenced by Kepone's greater solubility), Kepone also has a greater inherent affinity for the solid surface. In a very gross description, the PCBs are forced into the interfacial position between two matrices for which they have little inherent attraction by the overpowering repulsive forces exhibited by the water (hydrophobic interaction). Kepone probably maintains the same configuration but with lower interaction energetics.

TABLE A.6. INTERFACIAL TENSION CALCULATIONS (CASE 2)

a) $\sigma_{sw} = 2 \text{ ergs cm}^{-2}$

b) $\sigma_{sk} = \sigma_s + \sigma_k - 2\sqrt{\sigma_s^d \, \sigma_k^d}$

$= 10 \text{ ergs cm}^{-2}$

c) $\sigma_{kw} = 24 \text{ ergs cm}^{-2}$

The computations presented below represent the final modifications to the original K equation (Equation A-1) to account explicitly for the variations in natural particle sizes and content of organic matter. An attempt was made to limit the requirements of the final equations to parameters which are commonly measured. This has required the inclusion of certain empirical constants based on available data, and not solely on a priori theoretical considerations.

Dependence on Organic Content:

Previous considerations of adsorption energies on various types of particle surfaces indicate that pure inorganic surfaces should exhibit negligible adsorption of Kepone, while natural organic coatings on inorganic particles as well as organic detritus will exhibit adsorption energies equal to what was calculated previously. The problem then lies simply in correcting the surface area available for adsorption to reflect only that part which is organically coated.

The surface area occupied by a unit mass of natural organic matter, $A_c^{\dagger}$, was estimated from the values for a number of relatively simple alkanes, alcohols, and acids, which can reasonably be expected to represent component moieties of natural polyelectrolytes. These calculations are presented below:

where

$$\bar{A}_y = \pi r_y^2 \text{ No}$$

$$r_y = \left| \frac{3M_Y}{4\pi\rho_y \text{No}} \right|^{1/3}$$

$$A_y^{\dagger} = \bar{A}_y / M_y \text{ (units of cm}^2\text{/g)} \tag{A-4}$$

The values of $A_y^{\dagger}$ obtained for these compounds were relatively invariant, ranging from ∿0.7 cm^2/g to ∿3.0 cm^2/g. Therefore a rough average value of $A_c^{\dagger}$ = 2.0 cm^2/g was used for these estimates.

It was also recognized, however, that due to their polar nature as well as an entropic contribution from steric effects (coiling and uncoiling), the sorption of the natural organic matter would not be self-directing, i.e., accumulation is just as likely to occur on pre-sorbed organic matter as on free surface. At the same time, sorption of organic matter on itself would not alter the K-adsorption characteristics of the particle since it would not significantly change the amount of organic surface area. As a result, the effective specific surface area, i.e., that which is organically coated, A_c^*, can be expressed in terms of the total specific surface area, A_s^*, and the fractional organic content, P as a logarithmic expression.

$$A_c^* = A_s^* \left| 1 - \exp\left(-A_c^{\dagger} P / A_s^*\right) \right| \tag{A-5}$$

Dependence on Particle Size:

The simplest assumption one can make is that all of the particles are hard spheres. In this case, the area per particle, A_s, is found by simple geometry:

$$A_s = 4\pi r_s^2 \tag{A-6}$$

However, it is well recognized that natural particles are not spherical and generally have much larger surface areas than that predicted by Equation (A-6) as a result of pores and surface irregularities. Unfortunately, the latter contributions cannot be predicted from theory.

From recent field studies in Puget Sound, a correction factor, α, could be obtained by comparing the actual particle surface areas of sediments determined by N_2-BET adsorption, with particle radii determined as seive mesh sizes of the same sediment samples. Although it must be recognized that these data provide only a rough estimate, the total specific surface areas could generally be obtained by multiplying by 100 the surface areas calculated from the mesh sizes and assuming spherical particles; i.e. $\alpha = 1 \times 10^2$.

Using this figure, then,

$$A_s = \alpha 4 \pi r_s^2$$

$$m_s = \frac{4}{3} \pi r_s^3 \rho_s$$

and therefore

$$A_s^* = \frac{3\alpha}{r_s \rho_s} \quad \text{or} \left(\frac{6\alpha}{d_s \rho_s} \right) . \qquad \text{(A-7)}$$

Combining Equations (A-5) and (A-7) and substituting these for A_s^* in the original K equation yield the final form

$$K \equiv \frac{C_{y(s)}}{C_{y(w)}} = \frac{C^*_{y(s)} \beta}{C^o_{y(w)}} \qquad \text{(A-8)}$$

where

$$\beta = \exp \left| (E_s - E_m)/RT \right|$$

and

$$C_{y(s)} = \frac{A_c^* My}{\bar{A}_y} = \frac{6\alpha M_y \left| 1-\exp \; (-A_c^\dagger \, P d_s \rho_s / 6\alpha \right.}{d_s \rho_s \bar{A}_y} \qquad \text{(A-9)}$$

Based on these calculations and the energy terms presented in the previous report, Equation (A-9) was solved for Kepone partitioning on various sized particles at different organic loadings. The results are presented in Table A.7, and are presented as iso-K lines on a plot of particle size, d_s, versus percent organic matter, %P, in Figure A.1.

TABLE A.7. CALCULATED VALUES OF A_s^*, A_c^*, AND K FOR KEPONE BASED ON VARIOUS PARTICLE DIAMETERS, d_s, AND FRACTIONAL ORGANIC CONTENT, P

d_s	P	A_s^*	A_c^*	K
1.0000E-05	5.0000E-03	3.0000E+07	9.9834E+04	1.1975E+04
1.0000E-05	1.0000E-02	3.0000E+07	1.9933E+05	2.3911E+04
1.0000E-05	2.0000E-02	3.0000E+07	3.9735E+05	4.7663E+04
1.0000E-05	3.0000E-02	3.0000E+07	5.9404E+05	7.1258E+04
1.0000E-05	4.0000E-02	3.0000E+07	7.8943E+05	9.4695E+04
1.0000E-05	5.0000E-02	3.0000E+07	9.8352E+05	1.1798E+05
1.0000E-05	7.5000E-02	3.0000E+07	1.4631E+06	1.7551E+05
1.0000E-05	1.0000E-01	3.0000E+07	1.9348E+06	2.3209E+05
1.0000E-05	2.0000E-01	3.0000E+07	3.7448E+06	4.4921E+05
5.0000E-05	5.0000E-03	6.0000E+06	9.9171E+04	1.1896E+04
5.0000E-05	1.0000E-02	6.0000E+06	1.9670E+05	2.3595E+04
5.0000E-05	2.0000E-02	6.0000E+06	3.8696E+05	4.6417E+04
5.0000E-05	3.0000E-02	6.0000E+06	5.7098E+05	6.8491E+04
5.0000E-05	4.0000E-02	6.0000E+06	7.4896E+05	8.9841E+04
5.0000E-05	5.0000E-02	6.0000E+06	9.2111E+05	1.1049E+05
5.0000E-05	7.5000E-02	6.0000E+06	1.3272E+06	1.5920E+05
5.0000E-05	1.0000E-01	6.0000E+06	1.7008E+06	2.0402E+05
5.0000E-05	2.0000E-01	6.0000E+06	2.9195E+06	3.5021E+05
1.0000E-04	5.0000E-03	3.0000E+06	9.8352E+04	1.1798E+04
1.0000E-04	1.0000E-02	3.0000E+06	1.9348E+05	2.3209E+04
1.0000E-04	2.0000E-02	3.0000E+06	3.7448E+05	4.4921E+04
1.0000E-04	3.0000E-02	3.0000E+06	5.4381E+05	6.5232E+04

TABLE A.7. (Continued)

d_s	P	A_s^*	A_c^*	K
1.0000E-04	4.0000E-02	3.0000E+06	7.0221E+05	8.4234E+04
1.0000E-04	5.0000E-02	3.0000E+06	8.5041E+05	1.0201E+05
1.0000E-04	7.5000E-02	3.0000E+06	1.1804E+06	1.4160E+05
1.0000E-04	1.0000E-01	3.0000E+06	1.4597E+06	1.7510E+05
1.0000E-04	2.0000E-01	3.0000E+06	2.2092E+06	2.6500E+05
5.0000E-04	5.0000E-03	6.0000E+05	9.2111E+04	1.1049E+04
5.0000E-04	1.0000E-02	6.0000E+05	1.7008E+05	2.0402E+04
5.0000E-04	2.0000E-02	6.0000E+05	2.9195E+05	3.5021E+04
5.0000E-04	3.0000E-02	6.0000E+05	3.7927E+05	4.5495E+04
5.0000E-04	4.0000E-02	6.0000E+05	4.4184E+05	5.3001E+04
5.0000E-04	5.0000E-02	6.0000E+05	4.8667E+05	5.8379E+04
5.0000E-04	7.5000E-02	6.0000E+05	5.5075E+05	6.6065E+04
5.0000E-04	1.0000E-01	6.0000E+05	5.7860E+05	6.9405E+04
5.0000E-04	2.0000E-01	6.0000E+05	5.9924E+05	7.1881E+04
1.0000E-04	5.0000E-03	3.0000E+05	8.5040E+04	1.0204E+04
1.0000E-04	1.0000E-02	3.0000E+05	1.4597E+05	1.7516E+04
1.0000E-03	2.0000E-02	3.0000E+05	2.2092E+05	2.6500E+04
1.0000E-03	3.0000E-02	3.0000E+05	2.5940E+05	3.1116E+04
1.0000E-03	4.0000E-02	3.0000E+05	2.7915E+05	3.3486E+04
1.0000E-03	5.0000E-02	3.0000E+05	2.8930E+05	3.4703E+04
1.0000E-03	7.5000E-02	3.0000E+05	2.9798E+05	3.5744E+04
1.0000E-03	1.0000E-01	3.0000E+05	2.9962E+05	3.5941E+04
1.0000E-03	2.0000E-01	3.0000E+05	3.0000E+05	3.5986E+04
5.0000E-03	5.0000E-03	6.0000E+04	4.8667E+04	5.8379E+03

TABLE A.7. (Continued)

d_s	P	A_s^*	A_c^*	K
5.0000E-03	1.0000E-02	6.0000E+04	5.7860E+04	6.9405E+03
5.0000E-03	2.0000E-02	6.0000E+04	5.9924E+04	7.1881E+03
5.0000E-03	3.0000E-02	6.0000E+04	5.9997E+04	7.1969E+03
5.0000E-03	4.0000E-02	6.0000E+04	6.0000E+04	7.1973E+03
5.0000E-03	5.0000E-02	6.0000E+04	6.0000E+04	7.1973E+03
5.0000E-03	7.5000E-02	6.0000E+04	6.0000E+04	7.1973E+03
5.0000E-03	1.0000E-01	6.0000E+04	6.0000E+04	7.1973E+03
5.0000E-03	2.0000E-01	6.0000E+04	6.0000E+04	7.1973E+03
1.0000E-02	5.0000E-03	3.0000E+04	2.8930E+04	3.4703E+03
1.0000E-02	1.0000E-02	3.0000E+04	2.9962E+04	3.5941E+03
1.0000E-02	2.0000E-02	3.0000E+04	3.0000E+04	3.5986E+03
1.0000E-02	3.0000E-02	3.0000E+04	3.0000E+04	3.5986E+03
1.0000E-02	4.0000E-02	3.0000E+04	3.0000E+04	3.5986E+03
1.0000E-02	5.0000E-02	3.0000E+04	3.0000E+04	3.5986E+03
1.0000E-02	7.5000E-02	3.0000E+04	3.0000E+04	3.5986E+03
1.0000E-02	1.0000E-01	3.0000E+04	3.0000E+04	3.5986E+03
1.0000E-02	2.0000E-01	3.0000E+04	3.0000E+04	3.5986E+03
5.0000E-02	5.0000E-03	6.0000E+03	6.0000E+03	7.1973E+02
5.0000E-02	1.0000E-02	6.0000E+03	6.0000E+03	7.1973E+02
5.0000E-02	2.0000E-02	6.0000E+03	6.0000E+03	7.1973E+02
5.0000E-02	3.0000E-02	6.0000E+03	6.0000E+03	7.1973E+02
5.0000E-02	4.0000E-02	6.0000E+03	6.0000E+03	7.1973E+02
5.0000E-02	5.0000E-02	6.0000E+03	6.0000E+03	7.1973E+02

TABLE A.7. (Continued)

d_s	P	A_s^*	A_c^*	K
5.0000E-02	7.5000E-02	6.0000E+03	6.0000E+03	7.1973E+02
5.0000E-02	1.0000E-01	6.0000E+03	6.0000E+03	7.1973E+02
5.0000E-02	2.0000E-01	6.0000E+03	6.0000E+03	7.1973E+02
1.0000E-01	5.0000E-03	3.0000E+03	3.0000E+03	3.5986E+02
1.0000E-01	1.0000E-02	3.0000E+03	3.0000E+03	3.5986E+02
1.0000E-01	2.0000E-02	3.0000E+03	3.0000E+03	3.5986E+02
1.0000E-01	3.0000E-02	3.0000E+03	3.0000E+03	3.5986E+02
1.0000E-01	4.0000E-02	3.0000E+03	3.0000E+03	3.5986E+02
1.0000E-01	5.0000E-02	3.0000E+03	3.0000E+03	3.5986E+02
1.0000E-01	7.5000E-02	3.0000E+03	3.0000E+03	3.5986E+02
1.0000E-01	1.0000E-01	3.0000E+03	3.0000E+03	3.5986E+02
1.0000E-01	2.0000E-01	3.0000E+03	3.0000E+03	3.5986E+02

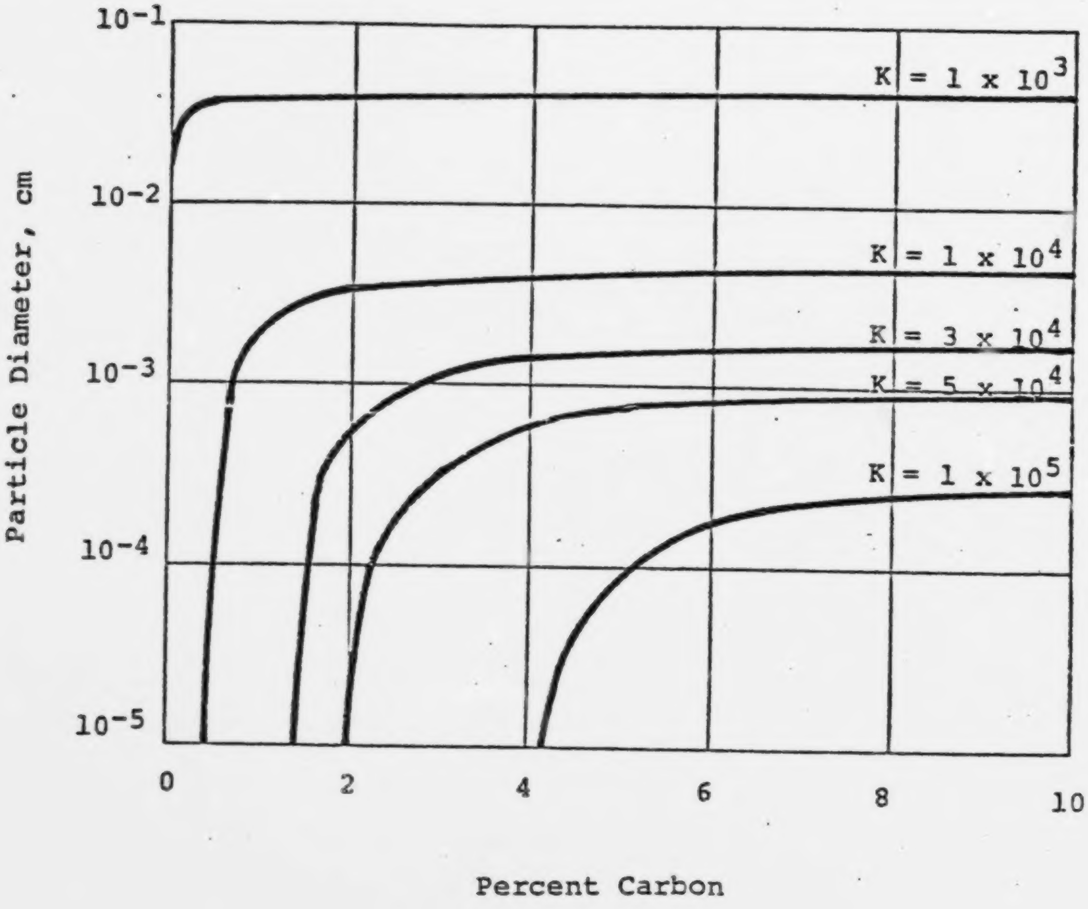

FIGURE A.1. Plots of K as a Function of Percent Carbon and Particle Diameter

The data indicate that for small particles, K is primarily dependent on the value of P. With the very large surface areas available on the small diameter particles, the majority of the natural organic matter at low values of P tends to accumulate on free surface, causing major changes in A_c^* , and thus K, with small changes in P. Conversely, with large particles, even a small fraction of organic matter is sufficient for complete surface coverage. As a result, A_c^* and K are essentially dependent entirely on the particle size, and independent of P.

For rough calculation purposes, the values in Table A-1 were reduced to account for the predicted partitioning between the major size fractions most commonly reported, sand, silt, and clay. This required that each of the latter fractions be assigned an approximate representative size. In this case, essentially median sizes were chosen: sand, d_s = 0.5 mm; silt, d_s = 50 μm; and clay, d_s = 5 μm. Based on these radii, K values for a number of organic loadings are presented in Table A.8. Obviously, the accuracy of these latter values is highly dependent on the actual size distributions.

TABLE A.8. THE COMPONENT CONCENTRATION RATIO, K, AS A FUNCTION OF THE PERCENT ORGANIC MATTER, %P, OF SAND, SILT, AND CLAY SUSPENDED PARTICULATES AND SEDIMENTS

Particle Size	K				
	%P				
	0.5	1	2	5	10
Sand	720	720	720	720	720
Silt	5,800	7,200	7,200	7,200	7,200
Clay	11,000	20,400	35,000	58,400	69,400

GLOSSARY

A_c^* = effective specific area, i.e., the specific area organically covered, cm^2/g_s

$A_c^\dagger$ = specific surface area of natural organic matter, cm^2/g_c

A_s^* = total specific surface area, cm^2/g_s

$\bar{A}_y$ = molar area of compound y, cm^2/mole

α = constant to account for increased surface area beyond that predicted from spherical particle calculations, unitless

β = BET energy term

d_s = effective particle diameter, cm

g_c = grams carbon/natural organic matter

g_s = grams sediment or suspended particulate matter

g_y = grams adsorbed organic compound, y

M_s = mass of particle, g

$N°$ = Avogadro's Number, 6.025×10^{23}

P = mass fraction of organic loading, g_c/g_s

ρ_s = density of sediment particles, g_s/cm^3

r_s = effective particle spherical radius, cm

M_y = molecular weight of compound y, g/mole

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APPENDIX A-2

THEORETICAL CONSIDERATIONS TO DETERMINE VOLATILITY LOSSES OF KEPONE THROUGH CODISTILLATION

Studies have shown that the rate of evaporation of relatively insoluble refractory organics is surprisingly high (Neely, 1976; Mackary and Walkoff, 1973). In fact, traces of pesticide are found in areas far away from any known applications. Two mathematical formulations have been developed to facilitate the quantitative projection of vaporization effects, one by Mackary and Walkoff (1973) and one by Liss and Slater (1974).

From the first of these, the rate constant for evaporation can be expressed from the following equation:

$$k = \frac{E \; P_v}{C_s} \, 18 \, \frac{M_i}{G} \, \frac{10^6}{P_w} \; hr^{-1} \qquad \text{(A-10)}$$

where

E = grams of water evaporating per hour

P_v = vapor pressure of pure material

M_i = molecular weight

C_s = solubility of organic (ppm)

G = grams of water containing the chemical

P_w = vapor pressure of water

18 = molecular weight of water

Using this method, the estimated losses of Kepone from surface waters can be calculated. Appropriate values for insertion in the equations are:

E = Evaporation rates of water for lakes in the middle latitudes vary between 1.5 mm/day and 4.5 mm/day with a yearly average of 800 to 2200 mm. If 1000 mm/yr evaporation rate is assumed here, this corresponds to an E value of 2740 g/m^2 day or $E = 114.17$ g/m^2-hr.

G = A depth of 1 meter was applied to unitize at 1 m^3 $G = 10^6$ g.

M_i = Molecular weight of Kepone $M_i = 490$ g.

C_s = Kepone solubility is 3 mg/ℓ (ppm) at neutral pH. The presence of solids leads to adsorption of dissolved Kepone until an equilibrium is reached between sorbed and dissolved concentrations. Hence, Bailey Bay water displays soluble levels of 0.016 μg/ℓ (ppb) and the River <0.006 μg/ℓ (ppb). The formulation requires solubility, not soluble level, therefore $C_s = 3$ ppm is employed.

P_w = Use vapor pressure of water at 20°C, $P_w = 17.535$ mm Hg.

P_v = Use vapor pressure for Kepone, $P_v = 2.5 \times 10^{-5}$ mm Hg.

This yields $k = 4.92 \times 10^{-5}$ g/hr (1.08×10^{-7} lb/hr) from a cubic meter (35 cubic feet) of water.

In the case of the second approach, Neely (1976) reports that the method is designed "...to measure the flux of various gases across the air-sea interface." Essentially, it calculates the rate constant for the movement of a gas in either direction across this interface; the method is based on the assumption that the exchanging gas obeys Henry's law (this assumption is also true for Method 1). Two equations (A-11) and (A-12) resulted from the derivation:

$$K\ (\text{liquid}) = \frac{H\ K_g\ k_\phi}{H\ k_g + k_\phi} \qquad \text{(A-11)}$$

$$K\ (\text{air}) = \frac{k_g\ k_\phi}{k_d + H\ k_g} \qquad \text{(A-12)}$$

where

K's are in units of (distance/time)

H is Henry's constant

(conc in gas phase)/(conc in liquid)

k_g and k are exchange constants

The two exchange constants, estimated from field data taken in the ocean by Schooley (1969) had a mean value of 3000 cm hr^{-1} for $k_g(H_2O)$ and 20 cm hr-1 for k (CO_2). In order to apply these constants to other materials, they should be multiplied by the ratio of the square roots of the molecular weights of H_2O and CO_2 with the gas in question.

The other parameter that needs to be evaluated is a number for Henry's constant. For slightly soluble materials in water the following relation is applicable:

$$P = \frac{X}{X_s} P_v \tag{A-13}$$

where

P = partial pressure of the organic

P_v = vapor pressure of pure organic

X = weight fraction of organic in water

X_s = solubility of organic in water

$$\frac{\text{weight of chemical}}{\text{weight of air}} = \frac{P}{P_t} \times \frac{M}{M_a} \tag{A-14}$$

where

P_t = partial pressure of air

M = molecular weight of organic

M_a = molecular weight of air = 29

Substituting the expression for P (A-13) into (A-14) yields (A-15)

$$(g/cm^3) \text{ air} = \frac{X}{X_s} \frac{P_v}{P_t} \frac{M}{29} \text{ density of air} \tag{A-15}$$

$$\text{or } H = \frac{(g/cm^3) \text{ air}}{(g/cm^3) \text{ water}} = \frac{P_v}{P_t} \frac{M}{29} \frac{\text{density of air}}{X_s} \tag{A-16}$$

For soluble materials the relation for P is given in (A-17).

$$P = X \frac{M(H_2O)}{M} P_v \tag{A-17}$$

Again, substituting this expression for P into (A-14) yields (A-18).

$$(g/cm^3)\ \text{air} = X\,\frac{18\ P_v}{29\ P_t} \qquad \text{(A-19)}$$

which on arranging gives

$$H = \frac{(g/cm^3)\ \text{air}}{(g/cm^3)\ \text{water}} = \frac{18\ P_v\ \text{density of air}}{29\ P_t} \qquad \text{(A-20)}$$

As evidenced in the above equations, to calculate the rate of evaporation using the techniques of Liss and Slater (1974) it is necessary to first calculate the mass flux of Kepone from water to air and the flux of Kepone from air to water. These calculations are possible using Equations (A-13) and (A-16) to solve Equations (A-11) and (A-12). The difference between (A-11) and A-12) will give the total mass flux, or in this case the net evaporation from the liquid.

Using these equations the Henry's constant H is calculated as 2.398×10^{-5} kg = 18.584, $K_{1ig} = 4.4 \times 10^{-4}$ and kg-K_{1ig} = 18.58 cm/hr. Using the same assumption of 1 m^2 of surface area, the volume of Kepone vapor generated in an hour is estimated to be 18.58 cm x 1.0 m^2 or .1858 m^3 of Kepone vapor. This vapor must be assumed to be at the vapor pressure of 2.5×10^{-6} mm Hg (25°C). From the partial pressure the mole fraction of Kepone in the air can be obtained, or:

$$\frac{2.5 \times 10^{-6}\ \text{mm Hg}}{760\ \text{mm Hg}} = 3 \times 10^{-9}\ \frac{\text{moles Kepone}}{\text{mole air}}$$

Using this and the molar volume of air and the molecular weight of Kepone, it is possible to give a mass flux of 1.336×10^{-5} g/hr.

The two values from the methods;

1) 4.92×10^{-5} g/hr based on water vapor loss rates and the Henry's Law constant

2) 1.34×10^{-5} g/hr based on differential vapor fluxes between the two phases.

are within a factor of 4. For two different theoretical calculations, the agreement is good. The calculated estimate of Kepone evaporation rates from water then is 1-5 x 10^{-5} g/hr based on a surface area of 1 m^2.

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APPENDIX B

SEDIMENT CORES DATA FOR THE JAMES RIVER

HAMPTON ROADS, JENNINGS LABORATORIES

Location	Station	Kepone ppm
Samples Taken at Pier 20 with Ponar Sampler Late in 1976	1	.011
	2	.011
	3	.009
	4	.007

Sample No.	Station No. 1 (5 ft)	Station No. 2 (8 ft)	Station No. 3 (7 1/2 ft)
1	0 -1.25 ppm	0 -1.5 ppm	0 -1.5 ppm
2	1.25-2.00 ppm	1.5 -2.5 ppm	1.5 -2.5 ppm
3	2.00-2.5 ppm	2.5 -3.75 ppm	2.5 -3.75 ppm
4	2.5 -3.25 ppm	3.75-5.25 ppm	3.75-5.25 ppm
5	3.25-4.0 ppm	5.25-6.0 ppm	5.25-6.0 ppm
6	4.0 -4.5 ppm	6.0 -6.5 ppm	6.0 -6.5 ppm
7		6.5 -7.0 ppm	6.5 -7.0 ppm
8		7.0 -7.5 ppm	

Sample No.	Station No. 1	Station No. 2	Station No. 3
1	33.58 ppb	15.26 ppb	16.18 ppb
2	40.14 ppb	28.60 ppb	32.66 ppb
3	22.86 ppb	10.77 ppb	4.56 ppb
4	13.99 ppb	2.93 ppb	4.11 ppb
5	7.99 ppb	2.81 ppb	4.08 ppb
6	7.48 ppb	3.70 ppb	3.17 ppb
7		3.01 ppb	2.46 ppb
8		3.01 ppb	

HAMPTON ROADS, VIMS

Location	Kepone ppm
Craney Island Disposal Area	.037
	.014
	.033
	.010
	.031
	.021
	.013
	.024
	.029
	.025
	.019
	.023
	.026
	.011
	.019
	.036
	.030
	.008
	.016
	.022
	.029

N = 21

$\overline{N}$ = .023

Std. Dev. = .009

HAMPTON ROADS, VIMS

Location	Date	Kepone ppm
Boat Basin West of Willoughby Bay	7/77	<.003
Boat Basin West of Willoughby Bay	3/77	.02
North of Craney Island Disposal Area	12/76	.012
	3/77	<.002
South of Newport News Point	12/76	.019
	3/77	.017
	7/77	.01

HAMPTON ROADS, DCLS (ppm)

	Station No.								
	4/76						3/76		
Inches	+46	47	48	49	50	51	Ace-1	Ace-2	Ace-3
0.0- 0.5	ND*	ND*	ND*	0.080	ND*	ND*	.08	0	0
0.5- 1.5	ND*	ND*	ND*	0.051	ND*	ND*	.051	0	0
1.5- 2.5				ND*					
2.5- 3.5				ND*					
3.5- 4.5									
4.5- 5.5									
5.5- 6.5									
6.5- 7.5									
7.5- 8.5									
8.5- 9.5									
9.5-10.5									
10.5-11.5									
11.5-12.5									
12.5-13.5									
13.5-14.5									
14.5-15.5									

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[*] ND - None detected at 0.02 ppm level of detection.

[**] ND - None detected at 0.01 ppm level of detection.

[+] State Water Control Board sample points.

JAMESTOWN ISLAND TO NEWPORT NEWS, VIMS

Location	Date	Kepone ppm
North of Pig Point	12/76	.019
	3/77	.017
	7/77	.01
James River Bridge	12/76	.013
	7/77	.096
Goodwin Point	12/76	.035
	3/77	.040
	7/77	.02
Mouth of Warwick River	12/76	.13
	3/77	.059
	7/77	.03
Mouth of Warwick River	7/77	.03
Above Days Point	12/76	.044
	3/77	.034
	7/77	.04
Burwell Bay	12/76	.057
	3/77	.075
Burwell Bay	12/76	.099
	3/77	.079
	7/77	.06
South of Mulberry Island	12/76	.025
	3/77	<.003
South of Mulberry Point	12/76	.083
	3/77	.063
	7/77	.055
South of Mulberry Point	12/76	.092
Near Mouth of Skiffes Creek	12/76	.13
	3/77	.11
	7/77	.096
Near Hog Island	12/76	.11
	3/77	.052
Below Jamestown Ilsnad	7/77	.074
Cobham Bay	12/76	<.017
	3/77	.019
Above Hog Island	7/77	.11

JAMESTOWN ISLAND TO NEWPORT NEWS, DCLS (ppm)

	Station No.														
	5/76									3/76			4/76		3/76
Inches	+31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
0.0- 0.5	0.028	0.16	0.12	0.12	0.09	0.057	ND*	ND*	0.28	0.071	0.047	ND*	0.03	0.032	ND*
0.5- 1.5	ND**	0.18	0.16	0.58	0.61	0.17	ND*	ND*	0.77	0.060	ND**	ND*	ND*	0.025	ND*
1.5- 2.5	ND**	0.06	ND**	ND*	0.12	ND*			0.24	0.02	ND*		0.03	ND*	
2.5- 3.5	ND**	0.10	ND**		0.14	0.02			ND*	ND*	ND*		ND*	ND*	
3.5- 4.5		0.11			0.19				ND**	ND*					
4.5- 5.5		0.10			0.14										
5.5- 6.5		0.11			0.21										
6.5- 7.5		0.12			0.26										
7.5- 8.5															
8.5- 9.5															
9.5-10.5															
10.5-11.5															
11.5-12.5															
12.5-13.5															
13.5-14.5															
14.5-15.5															

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*ND - None detected at 0.02 ppm level of detection.

**ND - None detected at 0.01 ppm level of detection.

+State Water Control Board sample points.

JORDAN POINT TO JAMESTOWN ISLAND, VIMS

Location	Date	Kepone ppm
Jamestown Island	12/76	.054
	3/77	.035
	7/77	.061
Swanns Point	7/77	.11
North Side of River Above Swanns Point	12/76	.12
	3/77	.13
	7/77	.12
South Side of River Above Swanns Point	12/76	.11
	3/77	.12
	7/77	.41
Barrets Point	7/77	.39
South of State Water Control Board Sample Point No. 25	7/77	.09
Near State Water Control Board Point No. 26	7/77	.11
Above Dancing Point	12/76	.17
	3/77	.21
	7/77	.20
Near Mouth of Upper Chippokes Creek	12/76	.20
	3/77	.11
	7/77	.17
Below Kennon Marsh	12/76	.079
	3/77	.12
	7/77	.13
Above Kennon Marsh	12/76	.12
	3/77	.11
	7/77	.10
Below Mouth of Ward Creek	12/76	.062
	3/77	.049
	7/77	.09
Mouth of Ward Creek	7/77	.09
Below State Water Control Board Sample Point No. 23	12/76	.07
	3/77	.051
	7/77	.09

Location	Date	Kepone ppm
Downriver Side of Windmill Point	7/77	.09
Upriver Side of Windmill Point	7/77	.01
Mouth of Herring Creek	7/77	.16
Above Mouth of Herring Creek	7/77	.01
Below State Water Control Board Sample Point No. 20	12/76	.014
	3/77	.009
Below Jordan Point	7/77	.03

JORDAN POINT TO JAMESTOWN ISLAND, JENNINGS LABORATORIES

Location	Date	Kepone ppm
Windmill Point Area	1/76	.41
Windmill Point Area	1/76	.81
Windmill Point Area	1/76	.87

RESULTS OF ANALYSIS FOR KEPONE OF THREE CORES FROM THE WINDMILL POINT SHOAL TAKEN JANUARY 25, 1976 BEFORE DREDGING

	A. Windmill Point Upstream End		B. Windmill Point Middle		C. Windmill Point Lower End	
Core Depth (in.)	Kepone (ppm)	%H_2O	Kepone (ppm)	%H_2O	Kepone (ppm)	%H_2O
0- 6	0.23	46.1	0.27	(b)	0.09	42.7
6-12	0.39	37.8	0.35	(b)	0.07	37.9
12-18	0.24	59.4	0.14	(b)	0.04	37.8
18-24	0.14	38.7	0.34	(b)	0.05	38.0
24-30	(a)	(a)	(a)	(a)	0.02	39.0

(a) Depth not samples.
(b) No analysis performed.

BELOW BENJAMIN HARRISON BRIDGE SOUTH SHORE, 18" CORE, DCLS

Core Depth	Date	Kepone ppm
0- 6	3/77	1.64
6-12		1.59
12-18		2.5

BELOW BENJAMIN HARRISON BRIDGE NORTH SHORE, 18" CORE, DCLS

Core Depth	Date	Kepone ppm
0- 6	3/77	.12
6-12		.13
12-18		.05

JORDAN POINT TO JAMESTOWN ISLAND, DCLS (ppm)

	Station No.												
	1/76						3/76			2/76			1/76
Inches	+18	19	20	21	22	23	24	25	26	27	28	29	30
0.0- 0.5	ND*	0.11	0.099	0.025	0.031	0.017	ND*	0.18	0.15	0.18	0.10	ND*	0.022
0.5- 1.5	ND*	0.08	0.13	0.022	0.013	0.054	0.04	0.49	0.45	0.088	0.090	ND*	0.001
1.5- 2.5		0.26	ND*	0.11	0.12	ND*	0.10	0.20	0.30	ND*	ND*		0.01
2.5- 3.5		0.86	0.35	0.03	0.12	ND*		0.20	0.13	ND*	ND*		ND*
3.5- 4.5		0.02	0.19	0.10	0.01			0.49	0.08				
4.5- 5.5		0.16	0.06	0.13	0.36			0.15	0.19				
5.5- 6.5		0.09	0.02	0.08	ND*			0.02	0.12				
6.5- 7.5		ND*	0.03	0.12	ND*			0.06	0.04				
7.5- 8.5			0.13	0.14				0.22	ND*				
8.5- 9.5													
9.5-10.5													
10.5-11.5													
11.5-12.5													
12.5-13.5													
13.5-14.5													
14.5-14.5													

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[*] ND - None detected at 0.02 ppm level of detection.

[**] ND - None detected at 0.01 ppm level of detection.

[+] State Water Control Board sample points.

JORDAN POINT TO RICHMOND, JENNINGS LABORATORY

Location	Date	Kepone ppm
Allied Chemical Pier	1/76	.46
Allied Chemical Pier	5/77	.04
Upriver Side of Jordan Point	5/77	.17
Bailey Bay South Shore Below Bailey Creek	5/77	5.05
Mouth of Bailey Creek	5/77	3.57
Mouth of Gravelly Run	5/77	.03
Marsh Area West Side of Bailey Creek	5/77	48.25
Marsh Area East of Bailey Creek Above State Highway 10	5/77	23.25
Bailey Creek Above Sewage Treatment Plant	5/77	8.10
Bailey Bay Approximate Center	5/77	.02

JORDAN POINT TO RICHMOND, VIMS

Location	Date	Kepone ppm
Upriver Side of Jordan Point	12/76	4.5
	3/77	.32
	7/77	.38
City Point	12/76	≤.005
	3/77	.017
	7/77	.00
Midway Between State Water Control Board Sample Points 4 and 13	12/76	.021
	3/77	.020
Below Jones Neck Cutoff	12/76	≤.006
	3/77	.010
	7/77	.02

JORDAN POINT TO RICHMOND, DCLS

Composit Cores 12" Long

Location	Date	Kepone ppm
Baileys Creek, Upstream from Hopewell Sewage Treatment Plant	12/75	0.1
100' Below No. 1	12/75	14.5
200' Below No. 1	12/75	24.0
300' Below No. 1	12/75	2.3
400' Below No. 1	12/75	1.6

JORDAN POINT TO RICHMOND, DCLS

Results of Kepone Analyses of James River Basin Sediment Core Samples Collected in January 1976. Kepone Values in ppm, DCLS.

Inches	Station No.									
	+1	2	3	4	5	6	7	8	9	10
0.0- 0.5	26.80	0.28	3.4	0.46	5.2	1.8	0.11	5.1	ND*	ND*
0.5- 1.5	23.80	0.41	1.1	0.15	1.3	0.13	0.22	3.4	ND*	ND*
1.5- 2.5	0.51	0.087	1.86	0.16	1.7	0.52	0.23	2.9		
2.5- 3.5	0.11	0.41	0.29	0.15	1.0	0.71	0.068	2.1		
3.5- 4.5				0.39	0.35	0.42	0.034	1.3		
4.5- 5.5				ND*	2.9	1.18	0.07	1.2		
5.5- 6.5				ND*	1.12	0.36	0.01	0.95		
6.5- 7.5					ND*		ND*	ND*		
7.5- 8.5					ND*			ND*		
8.5- 9.5										
9.5-10.5										
10.5-11.5										
11.5-12.5										
12.5-13.5										
13.5-14.5										
14.5-15.5										

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[*] ND - None detected at 0.02 ppm level of detection.

[**] ND - None detected at 0.01 ppm level of detection.

[+] State Water Control Board sample points.

JORDAN POINT TO RICHMOND, DCLS (ppm)

	Station No.						
Inches	+11	12	13	14	15	16	17
0.0- 0.5	ND*	0.058	0.020	0.006	ND**	ND**	ND**
0.5- 1.5	ND*	ND*	0.030	0.002	ND**	ND**	ND**
1.5- 2.5		ND*	0.19	0.07			
2.5- 3.5		ND*	0.17	0.06			
3.5- 4.5			0.02	0.07			
4.5- 5.5			0.10	0.12			
5.5- 6.5			0.17	ND*			
6.5- 7.5			ND*	ND*			
7.5- 8.5			ND*				
8.5- 9.5							
9.5-10.5							
10.5-11.5							
11.5-12.5							
12.5-13.5							
13.5-14.5							
14.5-15.5							

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*ND - None detected at 0.02 ppm level of detection.

**ND - None detected at 0.01 ppm level of detection.

+State Water Control Board sample points.

DATA NOT ON MAPS
(Sediment)

Six cores taken near the Surry Power Station, July 1976

Core No.	Depth (in.)	Kepone (ppm)
1	0 - 1/2	.12
1	1/2 - 1 1/2	.061
1	11 1/2 - 12 1/2	.12
2	0 - 1/2	.12
2	1/2 - 1 1/2	.081
2	4 - 5	.020
3	0 - 1 1/2	.34
3	1/2 - 1 1/2	.15
3	11 1/2 - 12 1/2	.14
4	0 - 1/2	.11
4	1/2 - 1 1/2	.063
4	11 1/2 - 12 1/2	.18
5	0 - 1/2	.27
5	1/2 - 1 1/2	.14
5	11 1/2 - 12 1/2	.12
6	0 - 1/2	.19
6	1/2 - 1 1/2	.026
6	11 1/2 - 12 1/2	≤.005

(Sediment)

Newport News Area:

Peterson Yacht Basin - September 1976 - .004 ppm

South End of Marshall Avenue - September 1976 - .0056, .0048 ppm

South End of Maple Avenue - September 1976 - .0045, .0028 ppm

Near Pier 15 - November 1976 - .026, .006 ppm

Near Ship Way No. 5 and 6 - October 1976 - .020, .025, .006 ppm

Craney Island Disposal Area:

December 1976 - .020, .039, .008, .035, .007, .011, .009 ppm

APPENDIX C

ENVIRONMENTAL AND LABORATORY SAMPLES

ENVIRONMENTAL SAMPLES EXTRACTED WITH TOLUENE:ETHYL ACETATE (1:3)

Sample No.	Date Extracted	Identification		
C-1-1	June 6, 1977	Bailey Creek Sediment Core	G-23	1 in. depth
2				2 in.
3				3 in.
4				4 in.
5				5 in.
6				6 in.
7				7 in.
8				8 in.
9				9 in.
10				10 in.
C-2-1	June 8, 1977	Bailey Bay Sediment Core	0-36	1 in.
2				2 in.
3				3 in.
4				4 in.
5				5 in.
6				6 in.
7				7 in.
8				8 in.
9				9 in.
10				10 in.
C-3-1	June 10, 1977		N-31	1 in.
2				2 in.
3				3 in.
4				4 in.
5				5 in.
6				6 in.
7				7 in.
8				8 in.
9				9 in.
10				10 in.
C-4-1	June 14, 1977		K-28	1 in.
2				2 in.
3				3 in.
4				4 in.
5				5 in.
6				6 in.
7				7 in.
8				8 in.
9				9 in.
10				10 in.
C-4-14	July 6, 1977			14 in.
19				19 in.
20				20 in.
L-26-1			L-26	1 in.
2				2 in.
3				3 in.
4				4 in.
5				5 in.

Sample No.	Date Extracted	Identification
L-26-6	July 6, 1977	Bailey Bay Sediment Core L-26 6 in. depth
7		7 in.
8		8 in.
0-38-1		0-38 1 in.
2		2 in.
3		3 in.
K-28 clay	July 7, 1977	Clay fraction K-28
0-36 clay		Clay fraction 0-36
K-28 sand		Sand fraction K-28
0-36 silt		Silt fraction 0-36
K-28 silt		Silt fraction K-28
N-31 silt		Silt fraction N-31
N-31 sand		Sand fraction N-31
0-36 sand		Sand fraction 0-36
0-38-5		Core 0-38 5 in. depth
6		6 in.
7		7 in.
8		8 in.
0-24-1	July 11, 1977	0-24 1 in.
2		2 in.
3		3 in.
4		4 in.
5		5 in.
6		6 in.
7		7 in.
8		8 in.
9		9 in.
10		10 in.
0-38-9		0-38 9 in.
10		10 in.
C-4-11		K-28 11 in.
12		12 in.
13		13 in.
15		15 in.
16		16 in.
17		17 in.
18		18 in.
0-19 0-12 in.	July 14, 1977	0-19 12 in. composite
0-34		0-34
P-35		P-35
M-32		M-32
N-33		N-33
0-30		0-30
N-35		N-35
N-27		N-27
P-33		P-33
P-37		P-37
N-39		N-39
M-30		M-30
Q-34		Q-34

Sample No.	Date Extracted	Identification		
L-29 0-12 in.	July 14, 1977	Bailey Bay Sediment Core	L-29	12 in. composite
M-34 ↓		↓	M-34	↓
L-31 ↓		↓	L-31	↓
O-32 ↓		↓	O-32	↓
O-28 ↓		↓	O-28	↓
Q-36 1-12 in.	July 19, 1977	↓	Q-36	11 in. composite
N-29 ↓		↓	N-29	↓
L-33 ↓		↓	L-33	↓
O-26 ↓		↓	O-26	↓
N-25 ↓		↓	N-25	↓
M-28 ↓		↓	M-28	↓
Pond Sed-3	July 20, 1977	Kepone Lagoon Sludge - 3		
2		Kepone Lagoon Sludge - 2		
1-NW		Kepone Lagoon Sludge - 1 - Northwest corner		
O-19-Stp-9		Sewer Pipe Slime		
I-17-Stp-7		Pump Station Slime		
P-19-Stp-8		Pump Station Slime		
EPA-RTP Samples	Sept. 29, 1977	EPA Round Robin Samples		
1-12		EPA Round Robin Samples		
S1-9-27-V1	Oct. 11, 1977	Nitrogen Park Soil	- Top inch	
V2		↓	- Second inch	
V3		↓	- Third inch	
V4		↓	- Fourth inch	
V5		↓	- Fifth inch	
V6		↓	- Sixth inch	
V7		↓	- Seventh inch	
V8		↓	- Eighth inch	
V9		↓	- Ninth inch	
V10		↓	- Tenth inch	
S6-9/27-V1		Soil from Field	- Top inch	
V2		↓	- Second inch	
V4		↓	- Fourth inch	
S2-9/27		Nitrogen Park Surface Soil		
S3-9/27-B	Oct. 11, 1977	Nitrogen Park Soil - Bare Surface		
-G		Nitrogen Park Soil - Grass Surface		
S4-9/27		Nitrogen Park Surface Soil		
S5-9/27		Life Science Site Soil		
JR8-S0830		James River Suspended Sediment		
S14-10/3	Oct. 13, 1977	Life Science Site Soil		
S13-10/3-V2-4		Disposal Field Soil - 2nd to 4th inches		
V1		Disposal Field Soil - Top inch		
S12-10/3-V1		PAN Site Surface Soil		
S13-10/3-V6-7		Disposal Field Soil - 6th to 7th inches		
GR-2 9/7		Allied Semi-Works Site Soil		
GR-8 9/7		Allied Soil near Gravelly Run		
GR-3 9/7		Allied Semi-Works Site Soil		
PS4-S-9/15	Oct. 25, 1977	Pump Station Slime		
PS3-S-9/15		↓		
PS10-S-9/15		↓		
PS1-S-9/15		↓		
Below PAN Dam 10/3		PAN Site Surface Soil		

Sample No.	Date Extracted	Identification
PS12-S-9/15	Oct. 25, 1977	Pump Station Slime
PS6-S-9/15		
PS5-S-9/15		
PS11-S-9/15		
PS8-S-9/15		
PS13-S-9/15		
PS2-S-9/15		
PS9-S-9/15		
PS7-S-9/15		
Laundry Pipe Slime 9/28		Slime from Laundry Pipe
Laundry Pipe Outlet 9/28		Soil Below Laundry Pipe Outlet
M-20 Gravelly Run at State Highway 20	July 7, 1977	Gravelly Run Sediment Core - 12 in. comp.
N-31 Clay		Bailey Bay Sediment Core - Clay Fraction
S8-9/27-V2	Oct. 27, 1977	Soil at Main Pump Sta. - Second inch
V6		- Sixth inch
V9		- Ninth inch
S11-9/27-V2		Soil at Western Pump Sta. - Second inch
V5		- Fifth inch
V10		- Tenth inch
S12-10/3-V10		PAN Subsurface Soil - 10 inches
PAN-P1	Nov. 29, 1977	Earth from PAN Quarry
P2		
P3		
P5		
2-5 ft		PAN Subsurface Soil - 5-foot depth
3-5 ft		
4-5 ft		
5-S		PAN Surface Soil
5-5 ft		PAN Subsurface Soil - 5-foot depth
6-5 ft		PAN Subsurface Soil - 5-foot depth
7-S		PAN Surface Soil
7-5 ft		PAN Subsurface Soil - 5-foot depth
8-5 ft		
9-5 ft		
T1-4 ft		- 4-foot depth
T1-5 ft		- 5-foot depth
T2-4½ ft		- 4½-foot depth
T2-5 ft		- 5-foot depth
T3-C		- 3-foot composite
T3-5 ft		- 5-foot depth
T4-5 ft		
T5-5 ft		
1-5 ft	Dec. 1, 1977	
T2-4½ ft		- 4½ foot depth
P4		Earth from PAN Quarry

Sample No.	Date Extracted	Identification
PAN-1-S	Dec. 9, 1977	PAN Surface Soil
2-S		
3-S		
4-S		
6-S		
8-S		
9-S		
S1-F0		Nitrogen Park Soil - Surface
F1		- 1-foot depth
F2		- 2-foot depth
F3		- 3-foot depth
F4		- 4-foot depth
F5		- 5-foot depth
F6		- 6-foot depth
F7		- 7-foot depth
F8		- 8-foot depth
F9		- 9-foot depth
F10		- 10-foot depth
S3-F0		Nitrogen Park Soil - Surface
F1		- 1-foot depth
F4		- 4-foot depth
F10		- 10-foot depth
S1-F1 Rerun	Dec. 12, 1977	- 1-foot depth
S3-F2		- 2-foot depth
F3		- 3-foot depth
F5		- 5-foot depth
F6		- 6-foot depth
F7		- 7-foot depth
F8		- 8-foot depth
F9		- 9-foot depth
LF-S1		Landfill Overburden
M-490	Dec. 19, 1977	
491		
492		
LF C2 Top 4 in.		Landfill Marsh Sediment Core - top 4-in.
C2 Mid 4 in.		- mid 4-in.
C2 Bottom 4 in.		- bottom 4-in.
C3 Top 4 in.		- top 4-in.
C3 Mid 4 in.		- mid 4-in.
C3 Bottom 4 in.		- bottom 4-in.
C5 Top 4 in.		- top 4-in.
C5 Mid 4 in.		- mid 4-in.
C5 Bottom 4 in.		- bottom 4-in.
A 0-1½ ft		PAN Subsurface Soil - Hole A
6-6½ ft		
9-10 ft		
14-15 ft		
19-20 ft		
25-26 ft		

Sample No.	Date Extracted	Identification
A 29-30 ft	Dec. 19, 1977	PAN Subsurface Soil - Hole A
34-35 ft		
39-40 ft		
49-50 ft		
B 4-5 ft	Jan. 3, 1978	PAN Subsurface Soil - Hole B
9-10 ft		
19-20 ft		
24-25 ft		
29-30 ft		
34-35 ft		
C 4-5 ft		PAN Subsurface Soil - Hole C
9-10 ft		
14-15 ft		
19-20 ft		
25-26 ft		
31-32 ft		
34-35 ft		
39-40 ft		
D 4-6 ft		PAN Subsurface Soil - Hole D
9-10 ft		
14-15 ft		
19-20 ft		
24-25 ft		
29-30 ft		
E 2-3 ft		PAN Subsurface Soil - Hole E
4-5 ft		
MC C1 1/5	Jan. 10, 1978	Moody Creek Sediment Core Section
C1 2/5		
C1 3/5		
C1 4/5		
C1 5/5		
C6 1/4		
C6 2/4		
C6 3/4		
C6 4/4		
C9 1/5		
C9 2/5		
C9 3/5		
C9 4/5		
C9 5/5		
LF C1 1/4		Landfill Sediment Core Section
C1 2/4		
C1 3/4		
C1 4/4		
C4 1/3		
C4 2/3		
C4 3/3		
UPRM C1 1/6	Jan. 12, 1978	Upper Poythress Run Marsh Sediment Core Section
C1 2/6		
C1 3/6		

Sample No.	Date Extracted	Identification
UPRM C1 4/6	Jan. 12, 1978	Upper Poythress Run Marsh Sediment Core Section
C1 5/6		↓
C1 6/6		
E 7-8 ft		PAN Subsurface Soil - Hole E
13-14 ft		↓
19-20 ft		
24-25 ft		
29-30 ft		
F 4-5 ft		PAN Subsurface Soil - Hole F
9-10 ft		↓
14-15 ft		
PAN Core 1 6 in.		PAN Sediment Core
2 8-16 in.		↓
3 0-10 in.		
3 10-20 in.		
4 1/2		
4 2/2		
Cattail Creek at sewer line		Cattail Creek Sediment Core
I-25 Bailey's K-X		Bailey Creek Marsh Sediment Core
J-25 Bailey's K-x		↓
F 19-20 ft	Jan. 17, 1978	PAN Subsurface Soil - Hole F
24-25 ft		↓
29-30 ft		
34-35 ft		
G 4-5 ft		PAN Subsurface Soil - Hole G
9-10 ft		↓
14-15 ft		
19-20 ft		
24-25 ft		
29-30 ft		
34-35 ft		
35-40 ft Comp		
H 4-5 ft		PAN Subsurface Soil - Hole H
9-10 ft		↓
14-15 ft		
19-20 ft		
24-25 ft		
29-30 ft		
34-35 ft		
39-40 ft		
44-45 ft		
49-50 ft		
BC C1 1/14	Jan. 20, 1978	Bailey Creek Mouth Sediment - Top inch
2/14		↓ - 2nd inch
3/14		- 3rd inch
4/14		- 4th inch
5/14		- 5th inch
6/14		- 6th inch

Sample No.	Date Extracted	Identification
BC Cl 7/14	Jan. 20, 1978	Bailey Creek Mouth Sediment - 7th inch
8/14		- 8th inch
9/14		- 9th inch
10/14		- 10th inch
11/14		- 11th inch
12/14		- 12th inch
13/14		- 13th inch
14/14		- 14th inch
A 37-39	Jan. 30, 1978	PAN Subsurface Soil - Hole A
35-37		
LF C-6-1		Landfill Sediment Core Section
C-6-2		
C-6-3		
C-7-1		
C-7-2		
C-7-3		
C-7-4		
C-8-4		
C-9-1		
C-9-2		
C-9-3		
C-9-4		
C-10-1		
C-10-2		
C-10-3		
C-10-4		
C-10-5		
C-8-1	Jan. 31, 1978	
C-8-2		
C-8-3		
C-11-1		
C-11-2		
C-11-3		
C-12-1		
C-12-2		
C-12-3		
C-12-4		
C-13-1		
C-13-2		
C-13-3		
C-13-4		
C-13-5		
C-13-6		
C-14-1		
C-14-2		
C-14-3		
C-14-4		
C-15-1		
C-15-2		

Sample No.	Date Extracted	Identification
LC C-15-3	Feb. 1, 1978	Landfill Sediment Core Section
C-15-4		↓
C-16-1		↓
C-16-2		↓
C-16-3		↓
E 10-11 SPT		PAN Subsurface Soil - Hole E
16-17 SPT		↓
M-1		Landfill Marsh 4-inch Sediment Grab
2		↓
3		↓
4		↓
5		↓
LF C-8-1	Feb. 8, 1978	Landfill Marsh Sediment Core Section
C-8-2		↓
C-8-3		↓
LF AG-1 F-1	Feb. 21, 1978	Landfill Marsh Sediment 1-ft depth
F-2		2-ft depth
F-3		3-ft depth
F-4		4-ft depth
F-5		5-ft depth
F-6		6-ft depth
F-7		7-ft depth
F-8		8-ft depth
F-9		9-ft depth
F-10		10-ft depth
LF AG-2 F-4		4-ft depth
F-6		6-ft depth
F-7½		7½-ft depth
F-9		9-ft depth
F-9½		9½-ft depth
F-10		10-ft depth
PAN AG-1 F-6		PAN Subsurface Soil - 6 ft depth
F-7		- 7 ft depth
M-6		Landfill Marsh 4-inch Sediment Grab
7		↓
8		↓
9		↓
PAN AG-2 F-4	Feb. 22, 1978	PAN Reservoir Sediment Section
F-6		↓
F-6½		↓
F-7		↓
F-8		↓
F-10		↓
PAN AG-3 F-2		↓
F-5		↓
F-6		↓
F-6½		↓

Sample No.	Date Extracted	Identification
PAN AG-3½ F-6½	Feb. 22, 1978	PAN Reservoir Sediment Section
F-7		↓
F-8		
F-9		
PAN AG-3 F-2½		
PAN AG-4 F-1		
F-3		
F-4		
F-5		
F-6		
F-7		
F-8		
F-9	Feb. 23, 1978	
PAN Core 5A 8 in.		PAN Sediment Core
S-20		Life Science Neighborhood Soil
21		↓
22		
23		
24		
25		
26		
27		
28		
29		
30		
31		
32		
33		
34		
35		
36		
37		
38		
39		
A 6-6½ SPT	Feb. 24, 1978	PAN Subsurface Soil - Hole A
19-20 SPT	(HCP Analysis)	↓
24-25 SPT		
29-30 SPT		
34-35 SPT		
39-40 SPT		
44-45 SPT		
49-50 SPT		
B 4-5 SPT		PAN Subsurface Soil - Hole B
9-10 SPT		↓
19-20 SPT		
24-25 SPT		
29-30 SPT		
34-35 SPT		

Sample No.	Date Extracted	Identification
G 4-5 SPT	Feb. 24, 1978	PAN Subsurface Soil - Hole G
9-10 SPT	(HCP Analysis)	↓
14-15 SPT		↓
19-20 SPT		↓
24-25 SPT		↓
29-30 SPT		↓
34-35 SPT		↓
35-40 Comp	Feb. 27, 1978	↓
H 4-5 SPT	(HCP Analysis)	PAN Subsurface Soil - Hole H
9-10 SPT		↓
14-15 SPT		↓
19-20 SPT		↓
24-25 SPT		↓
29-30 SPT		↓
34-35 SPT		↓
39-40 SPT		↓
44-45 SPT		↓
49-50 SPT		↓
PAN Core 5B 7.25 in.	Feb. 27, 1978	PAN Sediment Core
5C 7 in.		↓
6A 7.75 in.		↓
6B 7.5 in.		↓
6C 7.25 in.		↓
7A 8 in.		↓
7B 7 in.		↓
7C 7 in.		↓
Grit	March 14, 1978	Solids from STP Grit Chamber
Bailey Bay Beach		Wood Chips from Bailey Bay Beach
A 32-34		PAN Subsurface Soil - Hole A
PAN AG-1 F-1		↓ - 1-ft depth
F-4		↓ - 4-ft depth
MC C-8 Top 6 in.		Moody's Creek Sediment Core
C-7 Top 6 in.		↓
C-5 Top 6 in.		↓
C-4 Top 6 in.		↓
C-3 Top 6 in.		↓
C-2 Top 6 in.		↓

ENVIRONMENTAL SAMPLES EXTRACTED WITH PETROLEUM ETHER:ETHYL ETHER (1:1)

Sample No.	Date Extracted	Identification
C-1-2	July 19, 1977	Bailey Bay-Sediment Core 2 in. depth
P-13 Soil		Hopewell Surface Soil
W-11 Soil		
0-19-3		
M-20		
N-18		
0-19-1		
J-18		
N-16		
H-12	July 20, 1977	
0-19-2		
N-19		
F-20-KM		Bailey Creek Sediment Core
X-26		Hopewell Surface Soil
R-21		Hopewell Surface Soil
H-24 Bail KM		Bailey Creek Sediment Core
N-16	July 21, 1977	Hopewell Surface Soil
0-19-3		
P-13-Soil		
Special 3		
L-27-K 0-12 in.	July 26, 1977	Bailey Bay Sediment Core 12-in. Composite
M-26-K 0-12 in.		Bailey Bay Sediment Core 12-in. Composite
J-27-K 0-12 in.		Bailey Creek Sediment Core 12-in. Composite
G-23 Bail 0-12 in.		Bailey Creek Sediment Core 12-in. Composite
Marsh Below Landfill B-2 in. core		Landfill Marsh Sediment
Marsh Below Landfill A		
Marsh Below Landfill C		
I-25 0-12 in.		Bailey Creek Sediment Core 12-in. Composite
JR9 0-3 in. sand	July 29, 1977	James River Bottom Sediment-Sand Fraction
JR9 3-6 in. sand		
JR9 6-9 in. sand		
JR9 9-12 in. sand		
JR9 9-12 in. silt		-Silt Fraction
JR4 0-3 in. sand		-Sand Fraction
JR4 3-6 in. sand		
JR4 6-9 in. sand		
JR4 9-12 in. sand		
JR4 0-3 in. silt		-Silt Fraction
JR4 3-6 in. silt		
JR4 6-9 in. silt		
JR4 9-12 in. silt		
JR4 3-6 in. clay		-Clay Fraction
JR4 6-9 in. clay		
JR4 9-12 in. clay		
JR-9 0-3 in. silt	August 3, 1977	-Silt Fraction
JR-9 3-6 in. silt		
JR-9 6-9 in. silt		

Sample No.	Date Extracted	Identification
180 JR4-2-F	August 3, 1977	James River Suspended Sediment
181 JR-3-S		
182 JR9-S740		
183 JR1-1-S		
184 JR10-N1030		
185 JR1-3-S		
186 JR7-N0945		
187 JR1-3-E		
188 JR1-1-E		
JR8-C1600		
190 JR9-N0-0800		
191 JR1-3-F		
192 JR7-N-1320		
193 JR9-S-1140		
194 JR4-3-S		
195 JR8-1255		
196 JR10-N730		
197 JR4-1-F		
198 JR2-2-E		
199 JR4-2-S		
200 JR10-C1020		
L-27-K 0-12 in.	August 5, 1977	Bailey Bay Sediment Core 12 in. Composite
156 JR4-3-F		James River Suspended Sediment
157 JR10-N132		
158 JR8-C0900		
159 JR7-S0900		
160 JR10-S1240		
161 JR10-C1310		
162 JR9-C1102		
163 JR4-3-E		
164 JR7-C0920		
165 JR10-S645		
166 JR10-C0705		
167 JR9-N1200		
168 JR7-C-1620		
169 JR7-S-1235		
170 JR8-N1245		
171 JR10-S-930		
172 JR7-C1250		
173 JR7-S1600		
174 JR8 N0930		
175 JR9-C1360		
176 JR3-2-E		
177 JR9-C655		
203 BC1-1300	August 9, 1977	Bailey Creek Suspended Sediment
201 JR2-3		James River
202 BC-1700		Bailey Creek
178 JR9-N1420		James River
179 JR1-2-S		
JR-4 0-3 in. clay		James River Bottom Sediment-Clay Fraction

Sample No.	Date Extracted	Identification
JR-4 6-9 in. clay	August 9, 1977	James River Bottom Sediment - Clay Fraction
JR9 0-3 in. clay		
JR9 3-6 in. clay		
JR3-3-E	August 9, 1977	Suspended Sediment
JR2-3-S		
JR3-3-F		
JR4-1-S		
JR2-1-F		
JR2-1-S		
JR7-N1640		
JR2-3-E		
JR2-2-S		
JR2-2-F		
JR8-S-1530		
JR3-2-S		
JR4-2-E		
JR9-S1406		
JR3-1-S		
Q-23 0-12 in.	Aug. 18, 1977	Bailey Bay Sediment Core 12-inch
N-31 Sand (cent)		Bailey Bay Sediment Core - Sand Fraction
JR1-2-E		James River Suspended Sediment
JR1-1-F Kepone		
JR3-2-F		
JR2-1-E		
JR3-1-F		
JR4-1-E Kepone		
BC1-1030		Bailey Creek
JR3-1-E		James River
JR1-2-F		
H-24-R&L 0-12 in.		Bailey Creek Sediment Core
G-21 0-12 in.		
H-17 0-12 in. Cattail Cr above power line		Cattail Creek
F-19 R&L 0-12 in.		Bailey Creek
O-19 drainage ditch above Allied		Poythress Run
F-20-R&L 0-12 in.		Bailey Creek
P-21 L,M,R Drainage 0-12 in.		Poythress Run
N-31 silt (cent)	Aug. 22, 1977	Bailey Sediment Core - Silt Fraction
Q-17 soil	Aug. 30, 1977	Hopewell Surface Soil
G-29 soil		Hopewell Surface Soil
N-31 clay (cent)		Bailey Creek Sediment Core - Clay Fraction
JR-2 Station 1 12 in.	Sept. 22, 1977	James River Bottom Sediment
JR-8 1100 So. 12 in.		
JR-9 Vert 5 in. core		
JR-8 Center		
JR-2 Station 3 4 in. core		
JR-2 Station 2 12 in. core		
JR-4 Station 1 10 in. core		
JR-7 Center Ponar		
JR-9 Core Center 0840		
JR-4 Station 3 12 in. core		

Sample No.	Date Extracted	Identification	
JR-1 Station 2 12 in. core	Sept. 22, 1977	James River Bottom Sediment	
JR-10 1320 12 in. core			
JR-10 So. City Pt.			
JR-3 Station 1 12 in. core			
JR-3 Station 3 5 in. core			
JR-7 1130 So. 12 in. core			
JR-7 Center 1030 1 in. core			
JR-7 N1340 10 in.			
JR-1(?) Station 3 12 in. core			
JR-9 Center Ponar 1300			
JR-1 Station 1 12 in.	Oct. 5, 1977		
JR-4 Station 3 12 in.			
JR-10 Center 12 in.			
JR-9 North 1200 12 in.			
JR-3 Station 2 12 in.			
JR-9 1130 South 12 in.			
JR-7 S1100 Deep 12 in.			
JR-8 No 1230 12 in.			
EPA-RTP Samples 1-12		EPA Round Robin Samples	
S9-9/27-V1	Oct. 13, 1977	Soil at Appomattox Pump St.	Top Inch
SO-9/27-V2			Second Inch
S9-9/27-V3			Third Inch
S10-9/27		Surface Soil at Sussex Drive P.S.	
S7-9/27		Surface Soil at Dupont School	
Havens 2		STP Digester Sludge	
SLL-9/27-V1		Surface Soil at Western P.S.	
S8-9/27 V5		Soil at Main PUmp St.	Fifth Inch
S8-9/27-V1			Top Inch
S8-9/27-V10	Oct. 25, 1977		Tenth Inch
S8-9/27-V7			Seventh Inch
S8/9/27-V4			Fourth Inch
S8-9/27-V8			Eighth Inch
S8-9/27-V3			Third Inch
S11-9/27-V2	Oct. 27, 1977	Soil at Western P.S.	Second Inch
S11-9/27-V5			Fifth Inch
S11-9/27-V10			Tenth Inch
S12-10/3/V10		PAN Subsurface Soil	10 inches
S8-9/27-V2		Soil at Main Pump St.	Second inch
S8-9/27-V9			Ninth Inch
S8-9/27-V6			Sixth Inch

LABORATORY SAMPLES EXTRACTED WITH TOLUENE:ETHYL ACETATE (1:3)

Sample No.	Date Extracted	Identification
B-73 Mg Car	July 7, 1977	2 week sediment beaker tests with magnetic carbon
B-72		2 week sediment beaker tests with XAD-4 Resin
B-70		2 week sediment beaker tests with 863 Resin
B-71		2 week sediment beaker tests with XAD2 Resin
B-95	July 19, 1977	Sediment sample from 2 week beaker:Activated Carbon
C-97		Sediment extracted with caustic
C-111	July 26, 1977	pH adjusted sediments
B-135		4 week sediment beaker test with XAD2 Resin
B-133		4 week sediment beaker test with XAD4 Resin
B-134		4 week sediment beaker test with activated carbon
B-137		4 week sediment beaker test with magnetic carbon
B-136		4 week sediment beaker test with 863 Resin
LFA-285	August 30, 1977	Algae grown in landfarm #2 on contaminated sediment
GA-286		Sediment exposed to 155 megarads of γ radiation
LF3-283		Soil from landfarm #3 (tilled)
LF4-284		Soil from landfarm #4 (untilled)
278 100% ClO_2		Sediments contacted with 100% ClO_2, exposed to sun 69 hr
277 50% ClO_2		Sediments contacted with 50% ClO_2, exposed to sun 69 hr
BF-296		8 week sediment beaker test with activated carbon
279-blank		Sediments contacted with no ClO_2, exposed to sun 69 hr
B-328	Oct. 5, 1977	8 week sediment beaker test with XAD2 Resin
B-329		8 week sediment beaker test with 863 Resin
B-330		8 week sediment beaker test with XAD4 Resin
B-331		8 week sediment beaker test with magnetic carbon
LF-1-281		Soil from landfarm #1
ND-322		Final sediment natural dissolution experiment
ALF-321		UV blank sediment for amine test
ALF-305		Ethylenediamine landfarm sediment
MS-324		Run 2 Na_2CO_3 inlet carbon #2 molten salt
MS-323		Run 2 Na_2CO_3 inlet carbon #1 molten salt
LF2-282		Soil from landfarm #2 (1 in. watershed)
LF1-292		Carbon trap from landfarm #1
LF4-295		Resin trap (XAD4) from landfarm #4
B-334		12 week sediment beaker test with XAD4 Resin
B-332		12 week sediment beaker test with XAD2 Resin
ND-322	Oct. 11, 1977	Final sediment natural dissolution experiment
B-393		8 week beaker test blank
B-333	Oct. 13, 1977	12 week beaker test with 863 Resin
A-399		12 week beaker test sediment from activated carbon beaker
B-392		12 week beaker test blank

Sample No.	Date Extracted	Identification
C-434	Oct. 27, 1977	863 static column test 4th 1/2 inch
B-441		12 week beaker test solids (wet) magnetic carbon
B-438		4 week beaker test M863
B-439		4 week beaker test blank for M863
C-431		863 static column tests 1st 1/2 in.
C-432		863 static column tests 2nd 1/2 in.
C-433		863 static column tests 3rd 1/2 in.
B-440		12 week beaker test solids (dried) magnetic carbon
M-442		12 week beaker tests magnetic carbon sample
A-398		12 week beaker test activated carbon
LF2-293		Carbon from landfarm #2
LF3-294		XAD4 resin from landfarm #3
A		∿1 megarad of γ radiation on a sediment sample
B		∿10 megarad of γ radiation on a sediment sample
C		∿55 megarad of γ radiation on a sediment sample
S-470	Dec. 1, 1977	Test butyl amine landfarm solids
S-471		Test butyl amine landfarm solids blank
S-472		Solids from the 2nd natural dissolution test
B-473		8 week beaker test with M863 blank
B-474		8 week beaker test with M863 blank

LABORATORY SAMPLES EXTRACTED WITH PETROLEUM ETHER:ETHYLETHER (1:1)

Sample No. First Harvest Barley	Date Extracted	Identification		
6-20-1	July 26, 1972	Plant Uptake Tests,	First Growth Pattern	1
2				2
3				3
4				4
5				5
6				6
7				7
8				8
9				9
10				10
11	July 27, 1977			11
12				12
13				13
14				14
6-20-15	July 27, 1977			15
16				16
17				17
18				18
19				19
20				20
Second Harvest Barley				
7-7-1	July 27, 1977		Second Growth	1
2				2
3				3
4				4
5				5
6				6
7				7
8				8
9				9
10				10
11				11
12				12
13				13
14				14
15	July 29, 1977			15
16				16
17				17
18				18
19				19
20				20

Sample No.	Date Extracted	Identification
MS-151	Aug. 18, 1977	Activated carbon from molten salt extraction, 2nd stage, Run 1
MS-150		Activated carbon from molten salt extraction, 1st stage, Run 1
MS-215		Activated carbon from molten salt extraction, 2nd stage, Run 3
MS-155		Molten salt input for Run 1
MS-215		Activated carbon from molten salt extraction, 1st stage, Run 3
LF-238	Aug. 22, 1977	Final sediment of plowed landfarm
LF-239		Final sediment of unplowed landfarm
C-234		Static column test blank top 1 in.
C-235		Static column test blank 2nd inch
C-225		Static column test (XAD4 Resin) 1st 1/2 in.
C-226		Static column test (XAD4 Resin) 2nd 1/2 in.

APPENDIX D

LIST OF SPECIES IN THE TIDAL JAMES RIVER

LIST OF INVERTEBRATES AND FISHES OF THE TIDAL JAMES RIVER

(Nichols and Norton, 1969; U.S. AEC, 1974; Wass, 1972;
White et al., 1972; Larsen, 1974; VIMS, 1975)

PROTOZOA

Sarcodina

Ammoastuta salsa
Ammobaculites crassus
Ammobaculites crassus var. A.
Ammobaculites exigruus
Ammobaculites sp.
Ammonia beccarii var A.
Ammonia beccarii tepida
Arenoparella mexicana
Elphidium clavatum
Elphidium incertum
Haplophragmoides hancocki
Haplophragmoides manilaensis
Miliammina earlandi
Miliammina fusca
Minchinia nelsoni
Reophax nana
Tiphotrocha comprimata
Trochammina lobata
Trochammina macresceno
Trochammina squamata

COELENTERATA

Hydrozoa

Aselomaris michaeli
Blackfordia virginica
Bougainvillia rugosa
Campanulina sp.
Clytia cylindrica
Clytia edwardsi
Clytia hemisphaerica
Clytia kincaidi
Clytia paulensis
Cordylophora caspia
Dynamena cornicina
Eucheilota ventricularis
Ectopleura dumortieri
Eudendrium album
Eudendrium carneum
Eudendrium ramosum
Garveia cerulea
Garveia franciscana
Gonothyraea loveni
Halocordyle disticha
Hartlaubella gelatinosa
Hydra sp.
Hydractinia echinata
Lovenella gracilis
Moerisia lyonsi
Nemopsis bachei
Obelia bicuspidata
Obelia commissuralis
Opercularella pumila
Pennaria tiarella
Proboscidactyla ornata
Sertularia argentia
Turritopsis nutricula

Scyphozoa

Aurelia aurita
Boroe ovata
Chrysaora quinquecirrha
Cyanea capillata
Mnemiopsis leidye
Rhopilema sp.

Anthozoa

Astrangia danae
Diadumene leucolena
Edwardsia elegans

PLATYHELMINTHES

Turbellaria

Coronadena mutabilis
Euplana gracilis
Hydrolimax grisea
Stylochus ellipticus

RHYNCHOCOELA (=Nemertina)

Anopla

Cerebratulus spp.
Tubulanus pellucidus

Enopla

Amphiporus bioculatus
Tetrastemma elegans
Tetrastemma jeani
Zygonemertes virescens

ROTIFERA

BRYOZOA

Ctemostomata

Aeverrillia armata
Amathia vidovici
Anguinella palmata
Bowerbankia gracilis
Victorella pavida

Cheilostomata

Electra crustulenta
Membranipora tenuis

ENTOPROCTA

Pedicellina cernua

PHORONIDA

Phoronis architecta

ANNELIDA

Polychaeta

Ancistrosyllis jonesi
Aridicea wassi
Boccardia hamata
Ceratonereis irritabilis
Cirratulus grandis
Clymenella torquata
Drilonereis filum
Enoplobranchus sanguineus
Eteone heteropoda
Eumida sanguinea
Fabricia sabella
Glycera dibranchiata
Glycera americana
Glycinde solitaria
Gyptis vittata
Heteromastus filiformis
Hydroides dianthus
Laeonereis culveri
Lysippides gravi
Melinna maculata
Nereiphylla fragilis
Nereis succinea
Palaeonotus heteroseta
Parahesione luteola
Paraprionospio pinnata
Pectinaria gouldii

Polychaeta (continued)

Polydora ligni
Polydora sp.
Polydora websteri
Pseudeurythoe sp.
Sabella microphthalma
Sabellaria vulgaris
Scolecolepides viridis
Scoloplos fragilis
Spiochaetopterus oculatus
Streblospio benedicti
Syllida sp.
Tharyx setigera

Oligochaeta

Aulodrilus pigueti
Branchiura sowerbyi
Vero digitata
Ilyodrilus templetoni
Limnodrilus cervix
Limnodrilus hoffmeisteri
Limnodrilus spp.
Limnodrilus udekemianus
Nais spp.
Peloscolex gabriellae
Peloscolex heterochaetus
Peloscolex multisetosus
Stylaria lacustris

Hirudinea

Helobdella elongata
Illinobdella moorei

MOLLUSCA

Gastropoda

Acanthodoris pilosa
Acteocina canaliculata
Anachis avara
Anachis translirata
Cerithiopsis greeni
Cratena pilata
Crepidula convexa
Crepidula fornicata
Doridella obscura
Epitonium rupicolum
Eupleura caudata
Ferrissia sp.
Hydrobia sp.
Littorina irrorata
Mangelia plicosa
Melampus bidentatus
Melanella intermedia
Mitrella lunata

Gastropoda (Continued)

- *Nassarius obsoletus*
- *Nassarius vibex*
- *Odostomia bisuturalis*
- *Odostomia dux*
- *Odostomia impressa*
- *Pyramidella fusca*
- *Retusa canaliculata*
- *Rictaxis punctostriatus*
- *Skeneopsis planorbis*
- *Triphora nigrocincta*
- *Urosalpinx cinerea*
- *Valvata* sp.

Pelecypoda

- *Anadara ovalis*
- *Anadara transvera*
- *Anomia simplex*
- *Brachidontes recurvus*
- *Congeria leucophaeta*
- *Corbicula manilensis*
- *Crassostrea virginica*
- *Ensis directus*
- *Epitonium rupicolum*
- *Eupleura caudata*
- *Lyonsia hyalina*
- *Macoma balthica*
- *Macoma mitchilli*
- *Macoma phenax*
- *Mercenaria mercenaria*
- *Montacuta elevata*
- *Mulinia lateralis*
- *Mya arenaria*
- *Nucula proxima*
- *Polymesoda caroliniana*
- *Rangia cuneata*
- *Sphaerium transversum*
- *Tellina agilis*
- *Volsella demissa*
- *Yoldia limatula*

ARTHROPODA

Crustacea

Calanoida

- *Acartia clausii*
- *Acartia* sp.
- *Acartia tonsa*
- *Centropages hamatus*
- *Diaptomus reighardi*
- *Eurytemora affinis*

Calanoida (Continued)

- *Paracalanus parvus*
- *Pseudodiaptomus coronatus*

Harpactiocoida

- *Ectinosoma curticorne*
- *Ectinosoma* sp.

Cyclopoida

- *Cyclops* sp.
- *Cyclops vernalis*
- *Ergasilus labricis*
- *Eucyclops* sp.
- *Oithona similis*

Isopoda

- *Cassidinidea lunifrons*
- *Chiridotea almyra*
- *Cyathura burbancki*
- *Cyathura polita*
- *Edotea triloba*
- *Lironeca ovalis*

Amphipoda

- *Ampelisca abdita*
- *Ampelisca vadorum*
- *Ampithoe longimana*
- *Caprella penantis*
- *Corophium acherusicum*
- *Corophium lacustre*
- *Corophium tuberculatum*
- *Cymadusa compta*
- *Elasmopus levis*
- *Gammarus daiberi*
- *Gammarus fasciatus*
- *Gammarus mucronatus*
- *Lepidactylus dytiscus*
- *Leptocheirus plumulosus*
- *Listriella clymenellae*
- *Melita nitida*
- *Monoculodes edwardsi*
- *Paracaprella tenuis*
- *Paraphoxus epistomus*
- *Pleusymtes glaber*
- *Stenothoe minuta*
- *Sympleustes glaber*
- *Unicola irrorata*

- Cladocera
    - *Bosmina coregoni*
    - *Bosmina longirostris*
    - *Bosmina* sp.
    - *Cereodaphnia* sp.
    - *Diaphanosoma branchyurum*
    - *Daphnia parvula*
    - *Daphnia* sp.
    - *Leptodora kindtii*
    - *Podon* sp.
    - *Polyphemus pediculus*
- Cirripedia
    - *Balanus eburneus*
    - *Balanus improvisus*
    - *Chthamalus fragilis*
- Mysidacea
    - *Neomysis americana*
- Cumacea
    - *Cyclaspis varians*
    - *Diastylis* sp.
    - *Leucon americanus*
    - *Oxyurostylis smithi*
- Decapoda
    - *Callinectes sapidus*
    - *Crangon septemspinosa*
    - *Eurypanopeus depressus*
    - *Hippolyte pleuracantha*
    - *Macrobrachium ohione*
    - *Neopanope sayi*
    - *Neopanope texana*
    - *Ogyrides limicola*
    - *Palaemonetes pugio*
    - *Palaemonetes vulgaris*
    - *Panopeus herbstii*
    - *Penaeus duorarum*
    - *Penaeus setiferus*
    - *Pinnotheres ostreum*
    - *Rhithropanopeus harrisii*
    - *Uca minax*
    - *Upogebia affinis*

INSECTA

- Ephemeroptera
    - *Hexagenia mingo*
- Diptera
    - *Ablabesmyia* sp.
    - *Chaoborus punctipennis*
    - *Chironomus riparius*
    - *Cladotanytarsus* sp.
    - *Coelotanypus scapularis*
    - *Cruptochironomus fulvus*
    - *Dicrotendipes nervosus*
    - *Pelopia stellata*
    - *Polypedilum* sp.
    - *Procladium bellus*
    - *Smittia* sp.
    - *Stenochironomus taeniapennis*
    - *Stictochironomus devinctus*
    - *Tanytarsus* sp.
- Odonata
- Trichoptera
    - Arachnida
        - water mite
    - Pycnogonida
        - *Anoplodactylus pygmaeus*
    - Phoronida
        - *Phoronis architecta*
        - *Phoronis psammophila*

ECHINODERMATA

- Ophiuroidea
    - *Amphiodia atra*

HEMICHORDATA

CHORDATA

- Ascidiacea
    - *Molgula manhattensis*
- Osteichthyes
    - Acipenseridae
        - *Acipenser oxyrhynchus* (Atlantic sturgeon)
    - Amblyopsidae
        - *Chologaster cornuta* (swampfish)

Amiidae

Amia calva (bowfin)

Anguillidae

Anguilla rostrata
(American eel)

Atherinidae

Membras martinica
(rough silverside)
Menidia beryllina
(tidewater or glassy
silverside)

Menidia *menidia* (Atlantic
silverside)
Menidia sp.
(silversides)

Aphredoderidae

Aphredoderus sayanus
(pirate perch)

Batrachnoididae

Opsanus tau (oyster
toadfish)

Belonidae

Strongylura marina
(Atlantic needlefish)

Blennidae

Chasmodes bosquianus
(striped blenny)
Hypsoblennius hentzi
(feather blenny)

Bothidae

Paralichthys dentatus
(summer flounder)
Scophthalmus aquosus
(windowpane flounder)

Carangidae

Caranx hippos
(crevalle jack)

Centrarchidae

Lepomis auritus
(redbreast sunfish)
Lepomis gibbosus
(pumpkinseed)
Lepomis macrochirus
(bluegill)
Lepomis sp. (sunfish)
Micropterus dolomieui
(smallmouth bass)
Micropterus salmoides
(largemouth bass)
Pomoxis sp. (crappie)
Pomoxis nigromaculatus
(black crappie)

Clupeidae

Alosa aestivalis
(blueback herring)
Alosa pseudoharengus
(alewife)
Alosa mediocris
(hickory shad)
Alosa sapidissima
(American shad)
Brevoortia tyrannus
(Atlantic mennaden)
Dorosoma cepedianum
(gizzard shad)
Pomolobus aestivalis
(glut herring)
Dorosoma pentenense
(threadfin shad)

Cyprinidae

- *Clinostomus funduloides* (rosyside dace)
- *Cyprinus carpio* (carp)
- *Exoglossum maxillingua* (cutlips minnow)
- *Hybognathus* sp. (minnow)
- *Hybognathus nuchalis* (silvery minnow)
- *Notemigonus crysoleucas* (golden shiner)
- *Notropis bifrenatus* (bridle shiner)
- *Notropis hudsonius* (spottail shiner)
- *Notropis cornutus* (common shiner)
- *Rhinichthys atratulus* (Eastern blacknose dace)
- *Rhinichthys cataractae* (longnose dace)

Cyprinodontidae

- *Cyprinodon variegatus* (sheepshead minnow)
- *Fundulus luciae* (spotfin killifish)
- *Fundulus diaphanus* (banded killifish)
- *Fundulus heteroclitus* (mummichog)
- *Fundulus majalis* (striped killifish)

Engraulidae

- *Anchoa mitchilli* (bay anchovy)

Esocidae

- *Esox americanus* (grass pickerel)

Gasterosteidae

- *Gasterosteus aculeatus* (three-spined stickleback)

Gobiidae

- *Gobiosoma bosci* (naked goby)
- *Gobiosoma ginsburgi* (seaboard goby)
- *Microgobius thalassinus* (clown goby)

Gadidae

- *Urophycis regius* (spotted hake)

Gobiesocidae

- *Gobiesox strumosus* (skilletfish)

Ictaluridae

- *Ictalurus catus* (white catfish)
- *Ictalurus melas* (black bullhead)
- *Ictalurus natalis* (yellow bullhead)
- *Ictalurus nebulosus* (brown bullhead)
- *Ictalurus punctatus* (channel catfish)
- *Noturus gyrinus* (tadpole madtom)
- *Noturus insignis* (margined madtom)

Lepisosteidae

- *Lepisosteus osseus* (longnose gar)

Mugilidae

- *Mugil curema* (white mullet)

Percidae

- *Etheostoma fusiforme* (swamp darter)
- *Etheostoma nigrum* (Johnny darter)
- *Etheostoma olmstedi* (tessellated darter)
- *Etheostoma serriferum* (sawcheek darter)
- *Etheostoma* sp. (darter)
- *Perca flavescens* (yellow perch)
- *Percina notogramma* (stripeback darter)

Percidae (Continued)

Percina peltata
(shield darter)
Stizostedion vitreum vitreum
(walleye)

Petromyzontidae

Lampetra aepyptera
(least brook lamprey)
Petromyzon marinus
(sea lamprey)

Poeciliidae

Gambusia affinis
(mosquitefish)

Pomatomidae

Pomatomus saltatrix
(bluefish)

Sciaenidae

Bairdiella chrysura
(silver perch)
Cynoscion regalis
(weakfish)
Leiostomus xanthurus
(spot)
Micropogon undulatus
(Atlantic croaker)

Serranidae

Morone americana
(white perch)
Morone saxatilis
(striped bass)

Soleidae

Trinectes maculatus
(hogchoker)

Stromateidae

Peprilus alepidotus
(Southern harvestfish)
Peprilus triacanthus
(butterfish)

Syngnathidae

Syngnathus fuscus
(Northern pipefish)

Triglidae

Prionotus carolinus
(Northern searobin)

Umbridae

Umbra pygmaea
(Eastern mudminnow)

BIRDS AND MAMMALS

Common* Bird Species Found on the James River Wetlands

The following lists only those bird species which are commonly found in the wetlands along the James River. Many additional species of birds may occur in these wetlands in limited numbers or may erratically stop over in the marshes or swamps during migration. Species lists are available for Hog Island (Vepco, 1973) and Presquile National Wildlife Refuge (U.S. Department of the Interior, 1971), but a more comprehensive list of 223 species likely to occur in the open water or wetlands of the Lower Chesapeake Bay (Wass et al., 1972) includes all of the bird species likely to be found along the James River.

Common Name**	Scientific Name**
Hooded Merganser	*Lophodytes cucullatus*
Common Merganser	*Mergus merganser*
Red-breasted Merganser	*Mergus serrator*
Marsh Hawk	*Circus cyaneus*
Osprey	*Pandion haliaetus*
Clapper Rail	*Rallus longirostris*
Sora	*Porzana carolina*
American Coot	*Fulica americana*
Killdeer	*Charadrius vociferus*
Common Snipe	*Capella gallinago*
Spotted Sandpiper	*Actitis macularia*
Solitary Sandpiper	*Tringa solitaria*
Greater Yellowlegs	*Tringa melanoleucus*
Lesser Yellowlegs	*Tringa flavipes*

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*Abundance determined from: USDI (1971); Vepco (1973); Bystruk (1973 a, b; 1974 a, b; 1975 a, b; 1976 a, b).

**Nomenclature follows the fifth AOU check-list (Wetmore, 1957) and the thirty-second supplement (Eisenmann, 1973).

Common Name	Scientific Name
Dunlin	Calidris alpina
Semipalmated Sandpiper	Calidris pussillus
Herring Gull	Larus argentatus
Ring-billed Gull	Larus delawarensis
Laughing Gull	Larus atricilla
Bonaparte's Gull	Larus philadelphia
Great Black-backed Gull	Larus marinus
Forester's Tern	Sterna forsteri
Royal Tern	Thalasseus maximus
Barred Owl	Strix varia
Ruby-throated Hummingbird	Archilochus colubris
Belted Kingfisher	Megaceryle alcyon
Pileated Woodpecker	Dryocopus pileatus
Eastern Phoebe	Sayornis phoebe
Acadian Flycatcher	Empidonax virescens
Horned Grebe	Podiceps auritus
Pied-billed Grebe	Podilymbus podiceps
Great Blue Heron	Ardea herodias
Green Heron	Butorides virescens
Little Blue Heron	Florida caerulea
Great Egret	Casmerodius albus
Snowy Egret	Egretta thula
Black-crowned Night Heron	Nycticorax nycticorax
American Bittern	Botaurus lentiginosus
Canada Goose	Branta canadensis
Snow Goose	Chen caerulescens
Mallard	Anas platyrhynchos
Black Duck	Anas rubripes
Gadwall	Anas strepera
Pintail	Anas acuta
Green-winged Teal	Anas crecca
Blue-winged Teal	Anas discors
American Wigeon	Anas americana
Northern Shoveler	Anas clypeata
Wood Duck	Aix sponsa

Common Name	Scientific Name
Redhead	*Aythya americana*
Ring-necked Duck	*Aythya collaris*
Canvasback	*Aythya valisineria*
Lesser Scaup	*Aythya affinis*
Common Goldeneye	*Bucephala clangula*
Bufflehead	*Bucephala albeola*
Oldsquaw	*Clangula hyemalis*
Ruddy Duck	*Oxyura jamaicensis*
Fish Crow	*Corvus ossifragus*
Winter Wren	*Troglodytes troglodytes*
Long-billed Marsh Wren	*Telmatodytes palustris*
Gray Catbird	*Dumetella carolinensis*
Blue-gray Gnatcatcher	*Polioptilla caerulea*
White-eyed Vireo	*Vireo griseus*
Black-and-white Warbler	*Mniotilta varia*
Prothonotary Warbler	*Protonotaria citrea*
Northern Parula Warbler	*Parula americana*
Yellow-rumped Warbler	*Dendroica coronata*
Yellow-throated Warbler	*Dendroica dominica*
Prairie Warbler	*Dendroica discolor*
Louisiana Waterthrush	*Seiurus motacilla*
Kentucky Warbler	*Oporornis formosus*
Common Yellowthroat	*Geothlypis trichas*
Hooded Warbler	*Wilsonia citrina*
American Redstart	*Setophaga ruticilla*
Boblink	*Delichonyx oryzivorus*
Red-winged Blackbird	*Agelaius phoeniceus*
Rusty Blackbird	*Euphagus carolinus*
American Goldfinch	*Spinus tristis*
Swamp Sparrow	*Melospiza georgiana*

Mammals Which May Occur on the James River Ecosystem Based on Their Ranges*

Common Name	Scientific Name
Opossum	*Didelphis virginiana*
Southeastern shrew	*Sorex longirostris*
Least shrew	*Cryptotis parva*
Short-tailed shrew	*Blarina brevicauda*
Starnose mole	*Condylura cristata*
Raccoon	*Procyon lotor*
Longtail weasel	*Mustela frenata*
Mink	*Mustela vison*
Otter	*Lontra canadensis*
Striped skunk	*Mephitis mephitis*
Red fox	*Vulpes vulpes*
Gray fox	*Urocyon cinereoargenteus*
Bobcat	*Lynx rufus*
Gray squirrel	*Sciurus carolinensis*
Southern flying squirrel	*Glaucomys volans*
Beaver	*Castor canadensis*
Eastern harvest mouse	*Reithrodontomys humulis*
Rice rat	*Oryzomys palustris*
Meadow vole	*Microtus pennsylvanicus*
Muskrat	*Ondatra zibethica*
Eastern cottontail	*Sylvilagus floridanus*
White-tailed deer	*Odocoileus virginianus*

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*Source: Burt and Grossenheider (1976).

LIST OF ALGAE

(Jordan et al., 1976; Marshall, 1967; Ott, 1973; U.S. AEC, 1974; VIMS, 1973; Woodson, 1959, 1960)

CHLOROPHYTA (GREEN ALGAE)

Actinastrum hantzschii
Ankistrodesmus sp.
Bryopsis hypnoides
Chaetophora elegans
Cladophora callicoma
C. fascicularis
Closterium abruptum
C. acerosum
C. dianae
C. gracile
C. moniliforme
C. pritchardianum
Enteromorpha prolifera
Eremosphaera viridis
Eudorina elegans
Kirchneriella obesa
Micractinium pusillum
Microspora amoena
M. willeana
Oedogonium minor
Pandorina morum
Pediastrum duplex
P. integrum
Pleodorina californica
Pyramimonas sp.
Rhizoclonium hieroglyphicum
Scenedesmus obliquus
S. quadricauda
Spirogyra denticulata
S. insignis
S. protecta
Staurastrum gracilis
Stigeoclonium subsecundum
Tetraspora lubrica
Ulothrix tenerrima
Ulva lactuca

CYANOPHYTA (BLUEGREEN ALGAE)*

Anacystis cyanea
Lyngbya lutea
L. semiplena
Microcoleus vaginatus
Oscillatoria lutea
O. retzii
Phormidium retzii
Porphyrosiphon notarissi
Schizothrix arenaria
S. calcicola
S. tenerrima
Symploca atlantica

CHRYSOPHYTA (YELLOW-GREEN ALGAE)

Achnanthes sp.
Actinocyclus sp.
Amphiprora alata
Amphora sp.
Asterionella formosa
A. japonica
Bacteriastrum delicatulum
Biddulphia longricruris
B. mobiliensis
B. rhombus
Cerataulina bergonii (= *C. pelagica*)
Chaetoceros affinis
C. brevis
C. decipiens
C. gracilis
C. peruvianus
C. subtilis
Cocconeis scutellum
Corethron hystrix
Coscinodiscus spp.
C. asteromphalus
C. excentricus
C. lacustrus
C. lineatus
C. perforatus
Cyclotella striata
Diatoma hiemale
Eucampia zoodiacus
Eunotia sp.
Grammatophora marina
Guinardia flaccida
Gyrosigma sp.
G. balticum
G. fascicola
G. spencerii
Leptocylindrus danicus
Licmophora abbreviata
Lithodesmium undulatum
Melosira sp.
M. borreri
M. jurgensii
M. subsalsa
M. sulcata
Navicula sp.
N. mutica
N. tuscula
N. tyra
Nitzschia closterium
N. kutzingiana
N. longissima
N. paradoxa
N. punctata

(Chrysophyta, contd.)

- *N. pungens* var. *atlantica*
- *N. seriata*
- *N. sigma*
- *N. vermicularis*
- *Planktoniella sol*
- *Pleurosigma angulatum*
- *P. delicatulum*
- *P. formosum*
- *Rhaphoneis amphiceros*
- *Rhizosolenia alata*
- *R. calcar avis*
- *R. delicatula*
- *R. fragilissima*
- *R. minima*
- *R. setigera*
- *R. stolterfothii*
- *Skeletonema costatum*
- *Stephanopyxis turris*
- *Striatella* sp.
- *Suriella* sp.
- *Synedra* sp.
- *Thalassionema nitzschioides*
- *Thalassiosira nana*
- *T. nordenskioldii*
- *T. rotula*
- *T. subtilis*
- *Thalassiothrix longissima*
- *Vaucheria aversa*
- *V. sessilis*

PYRROPHYTA (DINOFLAGELLATES)

- *Amphidinium* sp.
- *Ceratium furca*
- *C. tripos*
- *Dinophysis* sp.
- *Diplosalis* sp.
- *Ebria tripartita*
- *Exuviaella* sp.
- *E. marina*
- *Glenodinium* sp.
- *Gonyaulax* sp.
- *Gymnodinium splendens*
- *Katodinium rotundatum*
- *Prorocentrum micans*
- *P. minimum*
- *P. triangulatum*

CRYPTOPHYTA

- *Chilomonas* sp.
- *Chroomonas* sp.
- *C. vectensis*
- *Cryptomonas salina*
- *C. stigmatica*

EUGLENOPHYTA (EUGLENOIDS)

- *Euglena* sp.
- *Eutreptia* sp.

PHAEOPHYTA (BROWN ALGAE)

- *Punctaria latifolia*
- *Sargassum hystrix* (adrift)

RHODOPHYTA

- *Batrachospermum virgatum*
- *Bostrychia radicans*
- *Ceramium rubrum*

*The marshes of the Atlantic coast of northern U.S. support an ubiquitous and rather uniform blue-green algal association (Ralph, 1977)

LIST OF THE VASCULAR FLORA

(Massey, 1961, Loetterle, 1970, Peloquin et al., 1975, U.S. AEC, 1974, U.S. Army Corps of Engineers, 1974, Wass, 1972, Radford et al., 1968)

Ophioglossaceae
- *Botrychium virginianum* Rattlesnake fern - swamps

Osmundaceae
- *Osmunda cinnamomea* Cinnamon fern - swamps, marshes, rare
- *O. regalis* var. *spectabilis* Royal fern - freshwater marsh, swamps, common

Pteridaceae
- *Pteridium aquilinum* Bracken fern - swales, rare

Aspidiaceae
- *Onoclea sensibilis* Sensitive fern - marshes and swamps
- *Polystichum acrostichoides* Christmas fern
- *Thelypteris noveboracensis* New York fern - swamps
- *T. palustris* Marsh fern - freshwater marshes

Blechnaceae
- *Woodwardia areolata* Netted chain-fern - wet woods and swamps

Pinaceae
- *Pinus echinata* Shortleaf pine
- *P. taeda* Loblolly pine
- *P. virginiana* Virginia pine

Taxodiaceae
- *Taxodium distichum* Bald cypress - Chickahominy River

Cupressaceae
- *Juniperus virginiana* Red cedar - marsh islands, salt tolerant

Typhaceae
- *Typha angustifolia* Narrow-leaved cattail - freshwater and oligohaline
- *T. latifolia* Common cattail - brackish marshes

Sparganiaceae
- *Sparganium americanum* Broad-fruited bur-reed - streams and shallow ponds

Zosteraceae
- *Zostera marina* Eelgrass - upper meso to euhaline

Potamogetonaceae
- *Potamogeton crispus* Curly pondweed - brackish water
- *P. pulcher* - muddy shores

Ruppiaceae
- *Ruppia maritima* Widgeon grass - fresh to euhaline

Najadaceae
- *Najas guadalupensis* Common water nymph - coastal waters

Alismataceae
- *Alisma subcordatum* Water plantain - muddy shores

Sagittaria falcata Duck potatoe - swamps
S. graminea Grassy arrowhead - marsh edges
S. latifolia Broad-leaved arrowhead - swamps
S. subulata Swl-leaved arrowhead - tidal swamps

Hydrocharitaceae
Elodea canadensis Waterweed - sluggish streams

Poaceae
Agrostis hyemalis Bent grass
Andropogon virginicus Broomsedge
Arundinaria gigantea Giant cane - swamps
Cenchrus tribuloides Thorny sandspur
Cinna arundinacea Stout woodreed - swamps
Danthonia sericea Oat grass
D. spicata Oat grass
Digitaria sanguinalis Hairy crabgrass - tidal marshes
Distichilis spicata Saltgrass - brackish marshes
Echinoclea crusgalli Barnyard grass - margins of brackish marshes
E. walteri Millet - edge of marshes
Elymus virginicus Virginia wild rye - tidal marshes
Festuca elatior Fescue
F. rubra Red fescue
Glyceria obtusa Blunt manna grass - marshes
G. striata Manna grass
Leersia oryzoides Rice cutgrass - marshes and swamps
Panicum amarulum Tall dune grass - sandy shores
P. amarum Short dune grass - sand dunes
P. commutatum Panic grass
P. dichotimiflorum Panic grass
P. scoparium Panic grass
Sacciolepis striata - wet soil near brackish marshes
Spartina alterniflora Saltmarsh cordgrass
S. cynosuroides Giant or Big cordgrass - brackish marshes
S. patens Saltmeadow cordgrass, saltmeadow hay
Trisetum pensylvanicum Three bristle - swamps
Triplasis purpurea Sand grass - dry sand
Tripsacum dactyloides Gamma grass
Uniola paniculata Sea oats
Zizania aquatica Wild rice - marshes

Cyperaceae
Carex alata Winged sedge - marshes and lowgrounds
C. albolutescens Light-yellow sedge - wet soil
C. baileyi Bailey's sedge - swamps
C. bromoides Oat sedge - swamps, moist woods
C. comosa Long-haired sedge - swamps
C. crinita Bearded sedge - lowground, swamps
C. decomposita - swamps
C. festucacea Stalked sedge - wet woods
C. glaucesens Sedge - wet soil and shallow water
C. howei Howe's sedge - swamps and wet thickets

C. hyalinolepis Clear-scale sedge - shores and swamps
C. incomperta Bog sedge - swamps
C. intumescens - wet soil
C. laevivaginata Smooth-sheathed sedge - wet woods
C. lupulina Hop sedge - wet woods
C. lurida Pale sedge - swamps
C. mitchelliana - wet soil, swamps
C. oxylepis Sharp-scaled sedge - moist swamps
C. rosea Rosy sedge - woodlands, moist meadows
C. scoparia - dry soil, open swamps
C. seorsa - wet woods
C. stipata Crowded sedge - swamps
C. typhina Cattail sedge - damp woods
C. venusta Charming sedge - boggy places
C. vulpinoidea Fox sedge - moist lowgrounds
Cladium jamaicense Saw grass - shallow water
Cyperus erythorhizos Red-root sedge - moist soil
C. esculentus Edible nutgrass - noxious weed, on dikes
C. filicinus - coastal marshes, wet sand
C. flavescens Pale-yellow sedge - ditches
C. grayi - dry sandy places
C. lancastriensis - moist woods
C. ovularis Oval sedge - wet soil
C. pseudovegetus Green sedge - wet soil
C. retrorsus Reflexed sedge - on dredged spoil
C. rotundus Round sedge - fields and waysides
C. strigosus Skinny sedge - common in wet areas
Dichromena colorata White-topped rush - shores and marshes
Dulichium arundinaceum Leafy joint sedge - swamps and shores
Eleocharis albida White spike-rush - moist soil
E. engelmannii - marshes
E. fallax Spike rush - brackish marshes and shores
E. obtusa Blunt spike-rush - wet soil
E. quadrangulata Squarestem spike rush - shallow water, river banks
E. tuberculosa - swamps
Fuirena squarrosa Perennial umbrella-grass - wet places
Rhynchospora capitellata Beak rush - moist lowgrounds, shores and woods
R. corniculata Horned rush - swamps
Scirpus americanus Common threesquare - fresh to saline marshes
S. atrovirens Black bulrush - bogs, wet places
S. cyperinus Woolgrass - wet places
S. fontinalis - wet lowgrounds and seepage
S. lineatus Bulrush - wet low areas
S. olneyi Olney threesquare - saline marshes
S. robustus Saltmarsh bulrush - coastal marshes
S. validus Great bulrush - shallow water

Araceae
Peltandra virginica Arrow-arum - brackish marshes

Lemnaceae
Lemna perpusilla Lesser duckweed - surface of still water, brackish water
Spirodela polyrrhiza Greater duckweed - still brackish marshes

Wolffia papulifera - surface of still water
W. punctata - still water

Eriocaulaceae
Eriocaulon parkeri Pipewort - muddy marshes
Lachnocaulon anceps Bog buttons - bogs and wet woods

Commelinaceae
Aneilema keisak - saline marshes

Pontederiaceae
Heteranthera reniformis Mud plantain - mud
Pontederia cordata Pickerel-weed - shallow water, muddy shores

Juncaceae
Juncus acuminatus - wet soil near streams
J. biflorus - wet meadows
J. bufonius Toad rush - wet situations
J. canadensis Canada rush - swampy places
J. coriaceus - wet open woods
J. effusus Soft-rush - meadows, wet places
J. elliottii - wet shores, low places
J. dicotomus - dry or moist areas
J. gerardi Black grass - saline marshes
J. griscomi - wet woods
J. platyphyllus - sandy soil
J. roemerianus Black needle-rush - saline marshes
J. scirpoides - moist areas, ditches
J. tennuis Path rush

Liliaceae
Lilium superbum Turks-cap lily - woods and waysides
Smilax bona-nox - thickets
S. hispida Hairy greenbriar - wet woods and swamps
S. laurifolia Big-leaf greenbriar - marsh edges
S. rotundifolia Common greenbriar - moist thickets
S. tamnifolia Carrion-flower - boggy places

Iridaceae
Iris prismatica Slender blue flag - lowgrounds, swamps
I. versicolor Blue flag - marshes, shallow pools
I. virginica Southern blue flag - wet soils, shallow pools
Sisyrinchium angustifolium Blue-eyed grass - moist meadows

Orchidaceae
Cypripedium acuale Pink lady's slipper - bogs
Habenaria ciliaris Yellow fringed-orchid - moist places
H. lacera Green fringed-orchid - open swamps, marshes
H. repens Water-spider orchid - wooded swamps
Marlaxis unifolia Green adder's mouth - meadows

Saururaceae
Saururus cernuus Lizard's tail - swamps, seepage areas

Salicaceae
Populus deltoides Cottonwood - stream and swamp borders

Salix nigra Black willow - shores, low grounds

Myricaceae
Myrica cerifera Wax myrtle - moist to wet soil

Juglandaceae
Carya glabra Sweet pignut hickory - moist woods
C. tomentosa Mockernut hickory - moist woods

Betulaceae
Alnus serrulata Tag alder - stream banks, swamps
Betula nigra River birch - along streams
Carpinus caroliniana Ironwood - stream banks

Fagaceae
Quercus alba White oak
Q. coccinea Scarlet oak
Q. falcata Southern red oak
Q. nigra Water oak - low grounds, marsh edges
Q. phellos Willow oak - borders of marshes
Q. rubra Red oak
Q. stellata Post oak
Q. virginiana Live oak - light soil along coast

Ulmaceae
Celtus occidentalis Hackberry - on dikes, marshes
Ulmus rubra Slippery elm - low woods bordering marshes

Moraceae
Morus rubra Red mulberry - alluvial woods

Urticaceae
Boehmeria cylindrica False nettle - moist soil
Pilea pumila Clearweed - moist woods

Loranthaceae
Phoradendron serotinum Mistletoe - parasitic on trees

Polygonaceae
Polygonum arifolium Halberd-leaved tearthumb - marshes
P. densiflorum Dense-flowered smartweed - wet woods and shores
P. hydropiperoides Water smartweed - shallow waters
P. lapathifolium - wet thickets, shores
P. punctatum Punctate smartweed - swamps
P. sagittatum Arrow-leaved tearthumb - moist soil, swamps
Rumex conglomeratus - waste places
R. crispus - waste places
R. obtusifolius Bitter dock - on dikes
R. verticillatus Swamp dock - in swamps

Chenopodiaceae
Chenopodium ambrosioides Mexican tea - waste lands

Salicornia europaea Glasswort - salt marshes and flats

Amaranthaceae
Amaranthus cannabinus Water hemp - salt marshes

Portulacaceae
Claytonia virginica Spring beauty - open woody areas

Caryophyllaceae
Stellaria media Common chickweed - ubiquitous weed

Ceratophyllaceae
Ceratophyllum demersum Coontail - ponds, quiet water

Cabombaceae
Brasenia schreberi Water shield - quiet waters

Ranunculaceae
Clematis virginiana Virgins bower - on dikes
Ranunculus abortivus Kidney leaf buttercup - in moist woods
R. pusillus Low spearwort - swamps
R. scleratus Cursed crowfoot - wet soil or shallow water
R. septentrionalis Northern buttercup - moist soil near streams
Thalictrum polygamum Meadow rue - moist meadows and swamps
T. revolutum - woods and thickets

Lauraceae
Lindera benzoin Spicebush - low grounds and along streams
Persea borbonia Red bay - moist woods along shores

Brassicaceae
Camelina microcarpa False flax
Cardamine bulbosa Swamp bittercress - wet meadows
C. pensylvanica Bittercress - dry places
Lepidium virginicum Poor-man's pepper - common weed
Rorippa icelandica Bog marsh-cress - on dikes

Hamamelidaceae
Liquidambar styraciflua Sweet gum - low ground woods

Platanaceae
Platanus occidentalis Sycamore - low grounds, near streams

Rosaceae
Amelanchier sp. Serviceberry - stream banks
Geum canadense Avens - open woods, floodplains
Prunus americana edges of woods
Rosa palustris Swamp rose - wet thickets, near brackish marshes

Fabaceae
Aeschynomene virginica - coastal flood-plain marshes
Apios americana Ground-nut - on dikes
Cassia fasciculata Partridge pea - light soils, marshes
C. nictitans Wild sensitive plant
Centrosema virginianum Butterfly pea - sandy banks of rivers

Lespedeza cuneata Sericea - on dikes
Robinia pseudo-acacia Black locust - colonizer on dredged disposal areas
Strophostyles helvola Dune bean - sandy beaches
S. umbellata Marsh bean - fresh to brackish tidal marshes
Trifolium repens White clover - wide spread

Polygalaceae
Polygala mariana Milkwort - moist areas

Callitrichaceae
Callitriche heterophylla Water starwort - shallow, quiet waters

Anacardiaceae
Rhus copallina Dwarf sumac - open areas, dry soils
R. radicans Poison ivy - freshwater marshes and transitional swamps
R. vernix Poison sumac - wet swampy places

Aquifoliaceae
Ilex opaca Holly - moist open woods
I. virticellata Winterberry - stream margins

Staphyleaceae
Staphylea trifolia Bladdernut - moist wooded borders and thickets

Aceraceae
Acer rubrum Red or swamp maple - moist woods, swamps

Balsaminaceae
Impatiens capensis Spotted touch-me-not, jewelweed - swamps, wet soil

Rhamnaceae
Berchemia scandens Supple-jack, rattan vine - wet to swampy areas, climber

Vitaceae
Parthenocissus quinquefolia Virginia creeper - swampy areas
Vitis rotundifolia Muscadine grape - moist soil
V. cinera Pigeon grape - moist soil
V. vulpina Frost grape - low ground thickets and stream banks

Malvaceae
Hibiscus moscheutos Marsh hibiscus - marshes
Kostėlėtskya virginica Seashore mallow - brackish marshes and shores

Hypericaceae
Hypericum dissimulatum St. John's-wort - moist sand
H. gentianoides - waste places
H. mutilum - moist places
H. virginicum Marsh St. John's-wort - bogs, swamps

Cistaceae
Hudsonia tomentosa Beach heather - coastal sand and dunes
Lechea racemulosa Pin-weed - dry soils

Lythraceae
Lythrum lineare Loosestrife - coastal marshes

Melastomataceae
Rhexia mariana Meadow beauty - moist coastal sand

Onagraceae
Ludwigia alternifolia Seedbox - moist areas
L. decurrens Primrose willow - on dikes
L. palustris Water purslane - wet soil of low meadows
L. uruguayensis Water primrose - on dikes
Oenothera perennis Sundrops - open ground

Haloragaceae
Myriophyllum brasiliense Parrot-feather - shallow water
M. pinnatum Water-milfoil

Apiaceae
Cicuta maculata Spotted cowbane, beaver poison - wet meadows, floodplains
Cryptotaenia canadensis Honewort - thickets
Daucus carota Queen Anne's lace - wodespread weed
Eryngium aquaticum - marshes and along shores
Hydrocotyle ranunculoides - streams
H. umbellata Water pennywort - wet soil along shores
H. verticillata Water pennywort - wet soil in marshes and open swamps
Lilaeopsis chinensis - coastal marshes
Oxypolis rigidior - swamps
Ptilimnium capillaceum Mock bishop's-weed - coastal marshes
Sium suave Water parsnip - wet areas

Nyssaceae
Nyssa aquatica Tupelo gum - swamp forests
N. sylvatica Black gum - sandy shores and low dunes

Cornaceae
Cornus amomum Dogwood - moist to wet soil near streams
C. sticta Swamp dogwood - swamps

Clethraceae
Clethra alnifolia Sweet pepperbush - swamps and borders of marshes

Ericaceae
Vaccinium atrococcum Black high-bush blueberry - wet woods, swamps
V. corymbosum Highbush blueberry - wet woods, swamps

Primulaceae
Lysimachia ciliata - woods and clearings
L. terrestris Swamp loosestrife - moist soil
Samolus parviflorus Water pimpernel - wet soil or shallow water

Plumbaginaceae
Limonium carolinianum Sea lavender - salt marshes
L. nashii Sea lavender - marshes

Ebenaceae
Diospyros virginiana Persimmon - old fields

Oleaceae
Fraxinus pennsylvanica Red ash - low grounds

Gentianaceae
Sabatia dodecandra Large marsh pink - coastal marshes
S. stellaris Sea pink - coastal marshes, sandy shores

Asclepiadaceae
Asclepias incarnata Swamp milkweed - wet soils
A. lanceolata Milkweed - coastal marshes
Cynachum laeve Sand-vine - sandy areas

Convolvulaceae
Cuscuta gronovii Dodder - on a variety of plants in low grounds

Boraginaceae
Cynoglossum virginianum Wild comfrey - waste places

Verbenaceae
Callicarpa americana Fresh mulberry - sandy moist woods
Lippia lanceolata Fog-fruit - sandy or light soil, marshes

Lamiaceae
Lycopus americanus Bugle-weed - moist to wet low grounds
L. virginicus - moist to wet soils
Scutellaria elliptica Skullcap - woodlands
Teucrium canadense Germander - moist soil

Solanaceae
Physalis virginiana Ground cherry - waste places
Solanum carolinense Horse nettle - waste places

Scrophulariaceae
Agalinis purpurea Purple gerardia - moise soil
Bacopa monnieri Water hyssop - coastal sands
Gratiola virginiana Hedge hyssop - shallow water in pools, stream margins
Linaria canadensis Toad-flax - dry fields
Mimulis alatus - wet woods, swampy floodplains
M. ringens - swampy floodplains
Veronica anagallis-aquatica - sluggish streams

Bignoniaceae
Campsis radicans Trumpet creeper - thickets

Acanthaceae
Justicia americana Water willow - intertidal marshes

Plantaginaceae
Plantago lanceolata Narrow-leaved plantain - widely distributed

Rubiaceae
Cephalanthus occidentalis Button bush - wet marshes, stream banks
Diodia virginiana Buttonweed - sandy fields
Galium circaezans - moist woods

Caprifoliaceae
Lonicera japonica Japanese honeysuckle - woodlands, roadsides, fence rows
Sambucus canadensis Elderberry - swamp forests
Viburnum cassinoides - moist to wet soil
V. dentatum - thickets and woods
V. nudum - swamps, wet woods

Cucurbitaceae
Melothria pendula Creeping cucumber - moist thickets

Campanulaceae
Lobelia cardinalis Cardinal flower - moist to wet meadows

Asteraceae
Aster dumosus Aster - moist to wet areas
A. puniceus Michaelmas daisy - moist areas
A. subulatus Wild aster - coastal marshes
A. tenuifolius Wild aster - coastal marshes, shores
A. vimineus
Baccharis halimifolia Sea myrtle - marsh borders
Bidens coronata Tickseed sunflower - moist low grounds
B. frondosa - Swampy ground
B. laevis Beggar-ticks - marshes, pools, ditches
Borrichia frutescens Sea ox-eye - edge of salt marshes
Carduus spinosissimus Yellow thistle - meadows
Eclipta alba - moist places
Erigeron bonariensis - waste places
E. pulchellus Robin's plantain - moist woods and meadows
Eupatorium capillifolium Dog fennel - moist to wet meadows
E. hyssopifolium Throughwort - dry openings
E. serotinum moist waysides
Helenium autumnale - near marsh margins
Iva frutescens Marsh elder - coastal salt marshes
Mikania scandens Climbing hempweed - brackish marshes
Pluchea camphorata Camphorweed - coastal marshes
P. foetida Marsh flea-bane - wet coastal areas
P. purpurascens Camphorweed - coastal salt marshes
Senecio aureus Golden ragwort - moist low grounds
Solidago altissima Golden rod - disturbed sites
S. sempervirens Golden rod - brackish to fresh coastal areas
Veronia glauca - moist open woods
V. noveboracensis - wet meadows, floodplains
Xanthium strumarium - Cocklebur - waste places

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APPENDIX E

BACKGROUND INFORMATION ON THE HOPEWELL-JAMES RIVER ENVIRONMENT

APPENDIX E

BACKGROUND INFORMATION ON THE HOPEWELL-JAMES RIVER ENVIRONMENT

A. HEALTH

Workers involved in the production of Kepone showed decided toxic symptoms from exposure to this substance (U.S. Department of Health, Education and Welfare, FDA, 1977). Kepone can enter humans by inhalation or ingestion of food that has become contaminated by bioaccumulation through the aquatic food chain. Calculated daily exposures to humans living in the James River area (excluding figures for worker exposure during the production of Kepone) range from 0.004 ng to 8.5 μg (Suta, 1977). The highest concentration levels would be from eating finfish, crabs and oysters. Atmospheric inhalation daily exposures to workers when Kepone was being produced were calculated to be about 750 μg (Suta, 1977).

B. RARE AND ENDANGERED BIOTA

Wildlife

Eight wildlife species considered endangered, status undetermined, or rare may be found in the James River or its associated wetlands (Table E.1). Of these eight, four species of birds are on the Federal list of endangered species (U.S. Department of the Interior, 1976). In addition, there are two status undetermined species of birds (U.S. Department of the Interior, 1973), and two rare species of amphibians (Taylor, 1974a) which may be found along the James River. Three of the six bird species have been reported in the James River area; the remaining three species of birds are likely to occur in the James River due to their mobility and the fact that they have been recorded in the Lower Chesapeake Bay (Wass, 1972). The two species of amphibians are expected to occur at Hog Island but have not been collected there yet (Vepco, 1973).

No state list of endangered species for Virginia has been developed to date. However, studies have been initiated under the Virginia Commission of Game and Inland Fisheries to look at the occurrence and distribution of candidate species for such a list. Initially, these studies will assess the populations of species on the Federal list of endangered species (U.S. Department of the Interior, 1976), but may eventually include other species such as those listed by Russ (1973).

Endangered Birds. The four species of birds listed as endangered, which may occur in the James River area during one or more seasons of the year are the brown pelican, southern bald eagle, American peregrine falcon, and Bachman's warbler (Table E.1). Of these birds, only the bald eagle and

TABLE E.1. ENDANGERED, STATUS UNDETERMINED, AND RARE WILDLIFE WHICH MAY OCCUR IN THE JAMES RIVER OR ITS ASSOCIATED WETLANDS

Common Name[a]	Scientific Name[a]	Status[b]	Recorded In[c] James River[d]	Recorded In[c] Lower Chesapeake Bay[e]
	Birds			
Brown Pelican	*Pelecanus occidentalis*	Fed. End.	--	Sp Su F
Southern Bald Eagle	*Haliaeetus l. leucocephallus*	Fed. End.	Sp Su F W	Sp Su F W
American Peregrine Falcon	*Falco percarinus anatum*	Fed. End.	Sp F	Su F W
Osprey	*Pandion haliaetus*	Undeter.	Sp Su F W	Sp Su F W
Wood Stork	*Mycteria americana*	Undeter.	--	Straggler
Bachman's Warbler	*Vermivora bachmanii*	Fed. End.	--	Straggler
	Amphibians			
Carpenter Frog	*Rana virgatipes*	Rare	Expected[f]	Dismal Swamp
Greater Siren	*Siren lacertina*	Rare	Expected[f]	Coastal Plain

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[a] Scientific nomenclature of birds follows Wetmore (1957) and Eisenmann (1973). Scientific nomenclature for amphibians follows Conant (1975).

[b] Fed. End. = on the Federal list of endangered species (U.S. Department of the Interior, 1976).
Undeter. = a species considered to be possibly threatened with extinction, but about which there is not enough information to determine its status (U.S. Department of the Interior, 1973).
Rare = considered to be rare in Virginia (Taylor, 1974a).

[c] Sp = Spring; Su - Summer; F = Fall; W = Winter

[d] Records of occurrence in U.S. Department of the Interior (1971) and Vepco (1973)

[e] Records of occurrence in Wass (1972) and Taylor (1974a)

[f] Expected to occur at Hog Island, although not actually seen (Vepco, 1973).

peregrine falcon are seen on any regular basis, and even these two species are not known to breed along the James River (M. L. Wass, personal communication, biologist, Virginia Institute of Marine Science).

The most current information on the bald egales nesting in the Chesapeake Bay region indicates that these raptors reached a 41-year high in the 1977 breeding season (U.S. Department of the Interior, 1977). Apparently that population is recovering from a severe decline that appears to be due to pesticides and other pollutants in their food. The James River, however, has not had nesting bald eagles since 1975, even though there were 13 breeding pairs as recently as 1964.

Peregrine falcons have not nested in Virginia since the early 1950's (Taylor, 1974b). The disappearance of breeding individuals coincided with the widespread use of chlorinated hydrocarbons, such as DDT. Healthy peregrines, however, still breed in Alaska and northern Canada, some of which pass through coastal Virginia during their southward migration. They are reported to occur rarely along the James River at Presquile National Wildlife Refuge (U.S. Department of the Interior, 1971).

Status Undetermined Birds. Both the osprey and wood stork are considered to be potentially threatened with extinction, but more information is needed to determine their true status (U.S. Department of the Interior, 1973). The wood stork has been recorded in the lower Chesapeake Bay area as a rare visitor (Wass, 1972), but has not been reported along the James River. The osprey, however, is frequently seen at Presquile National Wildlife Refuge during April and May (Mr. Olson, personal communication, Manager, Presquile) and is rarely seen at Hog Island Waterfowl Management Area (Vepco, 1973). The osprey no longer nests anywhere along the James River, although it is showing a slight population increase in the Chesapeake Bay (Olson and Wass, personal communication). The osprey's previous population declines appear to be due to the buildup of pesticides and their residues in the fish eaten by these top carnivores (Chamberlain, 1974).

Rare Virginia Amphibians. Two amphibians, the carpenter frog and greater siren, are reported to be rare in Virginia, but are expected to occur in the wetlands at Hog Island Waterfowl Management Area (Vepco, 1973 and Taylor, 1974a). The carpenter frog is present in limited numbers through Virginia's tidewater area, but is primarily limited to acidic sphagnum bogs (Taylor, 1974a). This frog can also be found in stands of emergent, grasslike vegetation (Conant, 1975). The greater siren lives in a variety of shallow water habitats in Virginia's coastal plain (Taylor, 1974a; Conant, 1975). These salamanders may be found in ditches, ponds, streams, swamps, and lakes which are associated with the James River.

Vascular Plants

There are no rare and endangered flowering plants of the tidal James River (Kartesz and Kartesz, 1977, L. G. Musselman, Old Dominion University, Biological Sciences Department, Norfolk, September 1977, personal communication).

C. SOILS

Movement of pesticides in soils is dependent on the adsorptive interactions between the chemical and soil properties (Guenzi, 1974). Soil erosion is an environmental factor pertinent to the movement of Kepone to the river. The soils within the city of Hopewell have not been characterized. However, the area adjacent to the city, east of Bailey Creek, is in the process of being surveyed. This discussion of these soils is based on unpublished data obtained from Mr. F. O. Kirks (U.S. Department of Agriculture, Soil Conservation Service, Prince George County, Virginia, October 17, 1977).

These soils are Ultisols, with eleven major soil series. Two of the series are lowland and poorly drained soils with slopes less than 2%. These are undeveloped floodplains of dark gray loam about 5 to 8 in. thick. The other nine series are the developed uplands which are moderately to well drained loam-clay-sand soils having slopes ranging from 0 to 45%. The upland soils support forests (about 60%) and agricultural lands (about 40%).

D. HISTORICAL AND ARCHEOLOGICAL FEATURES

In compliance with the National Historic Preservation Act of 1966 (16 U.S.C. 470), the U.S. Department of the Interior, National Park Service (1974) will be examined for the existing historical places within the area.

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APPENDIX F

APPLICABLE FEDERAL ENVIRONMENTAL STATUTORY MATERIALS AND REGULATIONS FOR STANDARDS

APPENDIX F

APPLICABLE FEDERAL ENVIRONMENTAL STATUTORY MATERIALS AND REGULATIONS FOR STANDARDS

A. FEDERAL ENVIRONMENTAL STATUTORY MATERIALS

Amendments to the National Environmental Policy Act and the Environmental Quality Improvement Act

Anadromous Fish Conservation Act, as amended, 16 U.S.C. 757a-757f

Bald and Golden Eagle Protection Act, as amended, 16 U.S.C. 668-668d

Clean Air Act, as amended, 42 U.S.C. 7401-7642

Coastal Zone Management Act of 1972, as amended, 16 U.S.C. 1451-1464

Endangered Species Act of 1973, as amended, 16 U.S.C. 1531-1543

Environmental Quality Improvement Act of 1970, as amended, 42 U.S.C. 4371-4374

Federal Food, Drug and Cosmetic Act, as amended, 21 U.S.C. 301-392

Federal Insecticide, Fungicide and Rodenticide Act, as amended, 7 U.S.C. 121-136y

Federal Land Policy and Management Act of 1976, 43 U.S.C. 1701-1782

Federal Water Pollution Control Act, as amended by the Clean Water Act, 33 U.S.C. 1251-1376

Fish and Wildlife Coordination Act of March 10, 1934, as amended, 16 U.S.C. 661-666c

Land and Water Conservation Fund Act of 1965, as amended, 16 U.S.C. 4601-4

Marine Protection, Research and Sanctuaries Act of 1972, as amended, Ocean Dumping, 33 U.S.C. 1401-1444

National Environmental Policy Act of 1969, as amended, 42 U.S.C. 4321-4361

National Historic Preservation Act of 1966, as amended, 16 U.S.C. 470-470t

Resource Conservation and Recovery Act of 1976, 42 U.S.C. 6901-6987

Rivers and Harbors Appropriation Act of 1899, as amended, 33 U.S.C. 401-466n

Safe Drinking Water Act, 42 U.S.C. 300f-300j-9

Solid Waste Disposal Act, as amended by Resource Conservation and Recovery Act, 42 U.S.C. 6901-6987

Toxic Substances Control Act, 15 U.S.C. 2601-2629

B. FEDERAL REGULATIONS FOR STANDARDS TO SPECIFIC POTENTIAL ENVIRONMENT POLLUTANTS

National Primary and Secondary Ambient Air Quality Standards, 40 CFR 40

*Occupational Safety and Health Administration Standards for Air Contaminants, 40 FR 27073

National Emission Standards for Hazardous Air Pollutants, 40 CFR 125

Emissions Standards for Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines, 40 CFR 85

National Interim Primary Drinking Water Regulations, 40 CFR 141

EPA Effluent Standards, 40 CFR 401

EPA Toxic Pollutant Effluent Standards (Proposed)

EPA Pesticide Limits, 40 CFR 162, 165

Criteria for the Evaluation of Permit Applications for Ocean Dumping of Materials, 40 CFR H, 220-229

Solid Wastes, 40 CFR 240

Dredge and Fill Material, 40 CFR 104

Coastal Zone Management Regulations, 15 CFR 923

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*Virginia adopted the federal standards on 23 September 1976.

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APPENDIX G

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APPENDIX H

ADDITIONAL DATA ON THE USE OF POLYMER FILMS

APPENDIX H

ADDITIONAL DATA ON THE USE OF POLYMER FILMS

FILM SELECTION

According to the Chemplex Company (Rolling Meadows, Illinois), who supplies the resin to Poly Tech, the resin used to produce the selected film is No. 2568, which has a density of 0.919 to 0.921 and a melt index of about 1.1. This suggests a reasonably high molecular weight, branched polymer. Both of these characteristics are advantageous for the present application. In addition, resin No. 2568 is routinely supplied with 100 to 400 ppm BHT (butylated hydroxytoluene) as antioxidant. Although the resin can be obtained without BHT, this is not advisable because the protection provided by the antioxidant during processing may help in maintaining optimum properties. On the other hand, versions of the resin containing slip additives and antiblock additives should be avoided. If antiblock agents should be necessary to improve handling characteristics, an inorganic additive such as diatomaceous earth is preferable to the usual organic additive, earucylamide.

LDPE (low density polyethylene) is hydrolytically stable and inert to a wide range of aqueous environments. It is also benign, if ingested by mammalian life forms. When exposed outdoors, oxidative degradation occurs, greatly accelerated by sunlight. Initial exposure to weathering conditions brings about crosslinking (Weichert and Kraus, 1968), which at a later stage turns into chain scission and embrittlement. Opacifying pigments, however, effectively inhibit this process (Stedman, 1969; Titus, 1968). LDPE is far better protected by 1% channel black than by UV-absorbing additives, and adequate protection of a black film has been demonstrated by a 25-year outdoor exposure in Florida (Winslow and Hawkins, 1967). It has also been shown that resins of relatively low melt index generally perform better with respect to aging than similar resins of higher melt index (Kaufman, 1967a, 1967b). However, other resin parameters must be considered in evaluating weathering or stress corrosion cracking resistance (Raff and Doak, 1964).

Information on seawater exposure of polyethylene is sparse. Claims have been made, however, that polyethylene films will last indefinitely in the underground damp-proofing and waterproofing of buildings (Jain and George, 1970). LDPE film found by fishermen off the Scandinavian coast indicate a high degree of deterioration (Holmstrom, 1975); however, the initial state of degradation of the clear film was attributed to sun and air exposure while the film floated on the surface of the sea. Other damage was attributed to the growth of organisms on the film surface. A study conducted at an ocean depth of 2370 feet included various polyethylene articles and foam (Muraoka, 1967). After more than a year, most polyethylene articles were in excellent condition while various other plastics were not.

Information on the effects of substances such as Kepone is not generally available. However, a report on storing water samples for determining pesticide content cautions against the use of polyethylene containers (Weil and Quentin, 1970). At concentrations of 10 $\mu g/\ell$ of water, insecticides such as DDT, dieldrin, heptachlor epoxide, lindane, and methoxychlor were completely adsorbed on the walls of polyethylene containers within 2 to 6 days. This suggests that Kepone ($C_{10}Cl_{10}O$) may also be adsorbed by polyethylene surfaces. The argument gains support from a statement by the Pesticide Chemicals Official Compendium (published by the Association of American Pesticide Control Officials, Inc.) that the hydrated form of Kepone is slightly soluble in hexane, though insoluble in water. On this basis it may be conjectured that a LDPE film would probably adsorb and concentrate any Kepone that may be dissolved in the water.

While there is general agreement that the Kepone concentration in the water is very low, it appears quite likely that dissolved Kepone will be deposited on the film surface and probably penetrate into the film. Since the polyethylene probably has an affinity for Kepone, it will not readily give it up to the water on the other side, and successful containment may be achieved for a considerable period of time.

An agent which can dissolve into the polyethylene morphology may increase the possibility of stress corrosion cracking. Point loading resulting from the gravel deposits may exert low, unevenly distributed strains. Such strains have, in recent years, been recognized as being disproportionately more severe than the high strain rates operating in the region of ductile yield generally encountered in plastic testing. An assessment of the effect of Kepone on the life expectancy of the film cannot be made without laboratory evalution, particularly in the absence of any data on the partition coefficient, rate of diffusion, and capacity of polyethylene for Kepone.

Unresolved questions remain regarding the performance of polyethylene film. These questions relate both to the physical characteristics of the resin used in the film and the interaction between the film and Kepone. However, it appears that a black-pigmented LDPE film prepared from a high-quality resin may be expected to have an extended life expectancy in an aquatic environment. Compared to year-round exposure on land, such a film would be subjected to milder temperature cycling and to reduced oxygen and UV exposure. Even over portions of the bay which become exposed to the air during low tides, it is likely that a silt deposit would soon shield the film from sunlight. A permanent overlay of sand or gravel would add to the life expectancy of the film.

Biological attack on the film needs to be considered unless the highly polluted conditions of Bailey Bay preclude the survival of most biota. Indications from the sparse literature are that LDPE can survive the ocean environment in most instances. However, special chains of events can lead to considerable biological attack as outlined in Holmstrom (1975). Experimental evaluation may be desirable/required to resolve the questions concerning the applicability of LDPE to the bottom-sealing system.

IMPLEMENTATION CONSIDERATIONS

The film-laying barge, shaped like a shallow "U" when viewed from above, is designed for a 3-inch draft to permit working in shallow water. The plastic film and gravel placing devices will be mounted in the open throat of the U. The bottom and sides of the hull will be constructed of reinforced aluminum sheet metal; the top of the hull will be thin fiberglass sheet to minimize weight.

The film-laying barge will be pulled by floating synthetic-fiber cables rather than being pushed by propellers or thrusters. In the shallow bay (3 feet or less) propellers or thrusters would disturb the Kepone-bearing sediment and would increase the draft of the barge, neither of which would be desirable. One of the cables will be attached to the service barge; the other two cables will be attached to positions on the bay shore, as shown in Figure H.1.

The film-laying barge will be pulled from the bay shore toward the service barge by means of a winch mounted on the deck of the service barge. It will be returned to shore by means of two winches mounted on the deck of the film-laying barge as shown in Figure H.2. These winches will maintain tension in two cables, each of which is attached to a "dead man" or a driven pile on shore. There are various ways in which the film-laying barge can be guided to follow a precise course between the shore and the service barge. One of the more accurate ways would be to use a laser beam as an aiming device to help the operator control the two retracting winches on the film-laying barge. The operator would observe the laser beam striking a plexiglas target. When the beam moved off target, indicating that the barge had moved off course, the operator would brake the winch on the cable toward which the barge needed to move to bring the barge back on course and the laser beam onto target.

The equipment for the film-laying operation will consist of the film-laying barge, a service barge, four 300-ton-capacity gravel barges, and a pair of movable "dead men" or anchor points on the shore. The service barge will support a 50-ton crane equipped with a 2-1/2-cubic-yard clamshell bucket, which will transfer gravel from the gravel barges into the slurry pumping system on the end of the service barge.

A typical operating scenario for the system is described in the following section.

OPERATING SCENARIO

The first task will be to clear the Bailey Bay shoreline from Jordan's Point to Gravelly Run of timber, driftwood, and other debris to a distance 10 feet back from the high-tide line. This debris, if not removed could get into the water during high water conditions and damage the emplaced plastic film. Also a clear shoreline is needed for laying the film above the high-tide line and for anchoring the guiding cables.

Two approaches to the film-laying operation have been considered. The first approach required dredging a 2-mile channel across the mouth of Bailey Bay to allow conventional gravel barges to lay alongside the service barge at low tide. This channel will be connected to the James River by means of similar but shorter access channels (see Figure H.1), which will allow the gravel barges to be brought into the Bailey Bay channel from the river. Although this approach would disturb the bottom sediment of Bailey Bay, which may contain pollutants other than Kepone that would be carried into the James River, the film-laying support equipment would be kept out of the main river channel and, therefore, would not present a navigation hazard.

In the second approach, the support equipment would be positioned in the James River channel. This would avoid a dredging operation, but would require positioning the support equipment on the outside of a bend in a river that may carry heavy barge traffic during the film-laying operation.

Essentially the same equipment would be used in both approaches. The major equipment difference would be the requirement in the second approach for more slurry pipeline and a booster slurry pump to be located midway between the service barge and the film-laying barge. In both approaches, film would be placed on the bay bottom and partially covered with gravel by the shallow-draft barge designed especially for the job.

The plastic film will be laid by the barge in the following manner. The film will be stored at the base of the U, transverse to the sides, in two 20-foot wide rolls mounted side-by-side, as shown in Figure H-2. While the film-laying barge moves from the shore to the service barge, the film will be unreeled from one roll at a time by a pair of rollers in much the same way a bed sheet is pulled through a washing-machine wringer. The lower roller will perforate the sheet to permit the sediment to outgas.

The film-laying operation will proceed across the current, with subsequent laying passes upcurrent from the previous pass. This will ensure that the current does not lift the free edge of overlapped film strips. The film will be 20 feet wide, with each strip overlapping the previously laid strip by about 3 feet, giving an effective strip width of 17 feet. The laying length will be from 1/2 to 3/4 mile. Additional film will be loaded onto the film-laying barge as required from the service barge.

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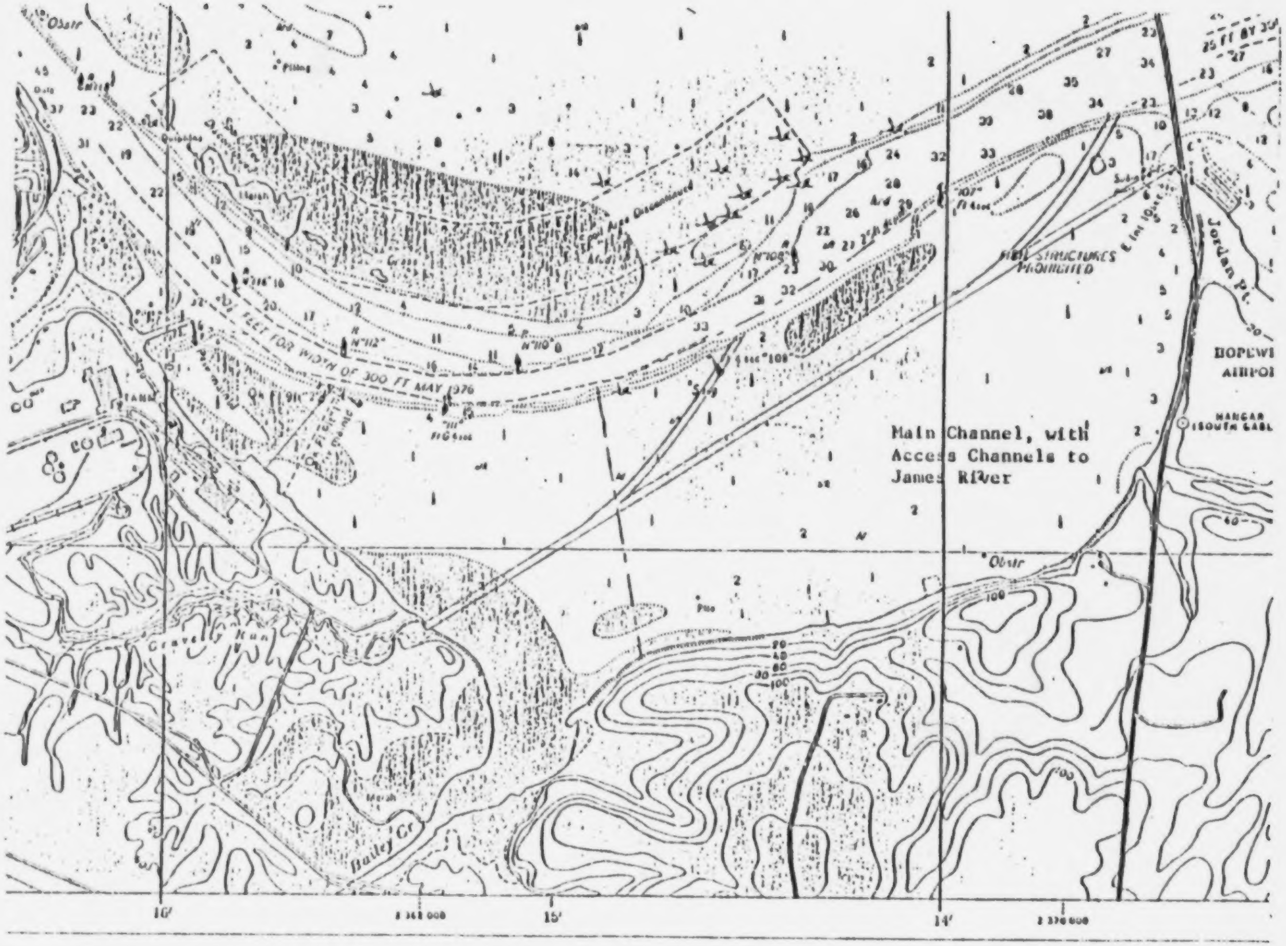

Main Channel, with Access Channels to James River

Jordan Pt.
HOPEWELL AIRPORT
HANGAR (SOUTH GABL
Obstr
Gravelly Run
Bailey Cr
27 FEET FOR WIDTH OF 300 FT MAY 1976
STRUCTURES PROHIBITED
16'
15'
14'

FIGURE H.1. Bailey Bay, Showing Channels to be Dredged

Reproduced from
best available copy.

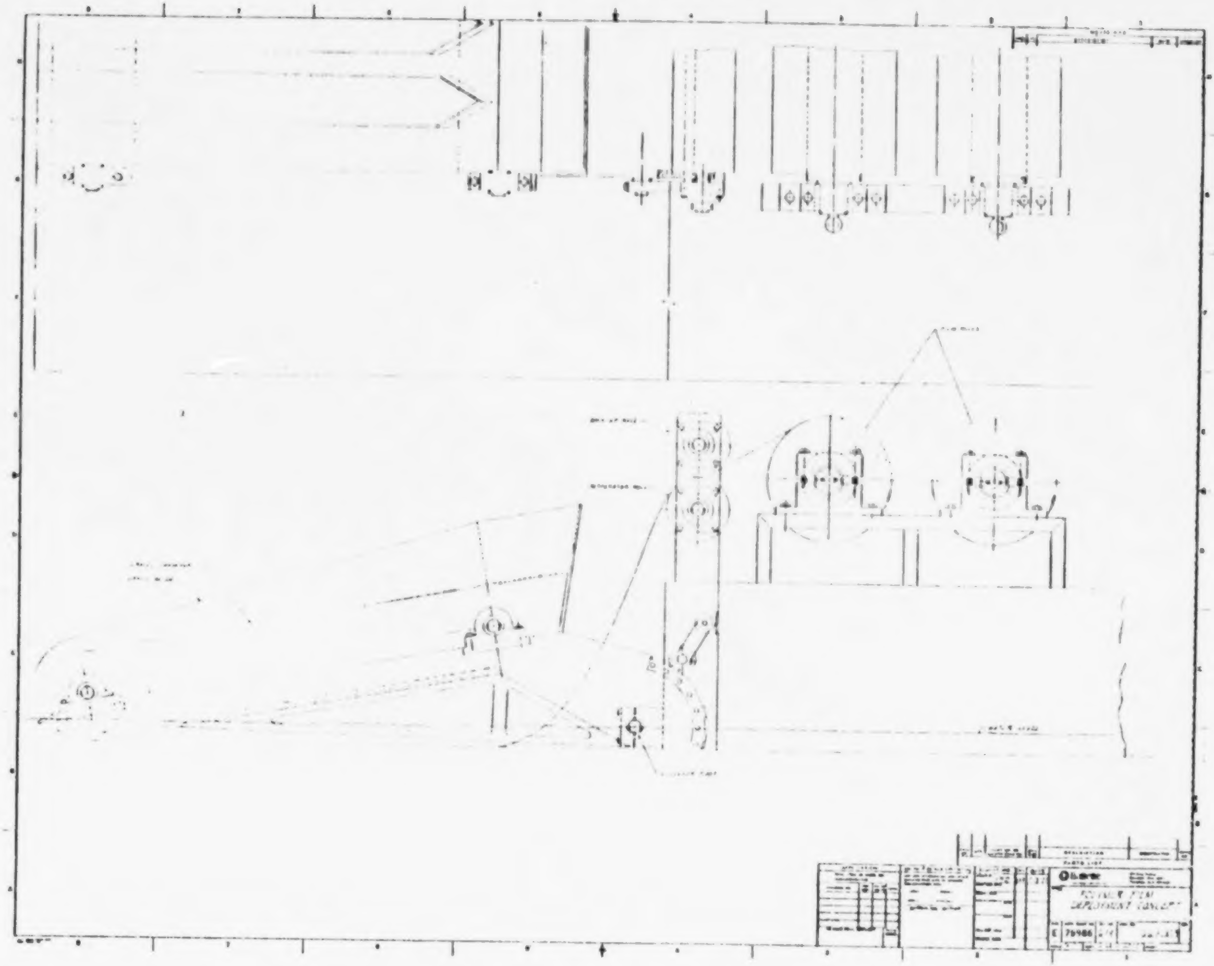
POLYMER FILM
DEPLOYMENT CONCEPT
C
79486

FIGURE H.2. Polymer Film Deployment Concept

The film, released close to the bottom, will be caused to sink onto the sediment by the gravel. The gravel, which will hold the plastic film on the bottom, will be pumped from the service barge to the film-laying barge as a slurry, It will be dispensed onto the plastic by means of a large, open, fan-shaped nozzle which will split the slurry flow into several smaller streams, and a conveyor belt, which will help place these streams gently onto the top of the plastic. Both the rolls and the conveyor belt will be driven by hydraulic motors which will be driven by a small air-cooled diesel-hydraulic power supply.

When the film-laying barge has reached the end of its travel in laying a strip of plastic, the anchor points for its propulsion cables will be moved if required. The service barge will be moved 17 feet upcurrent by adjusting its moorings or by moving it with a tugboat. On the shore, the laser source and the two "dead men" will also be moved 17 feet upcurrent.

The film near the shoreline must be covered completely with gravel and/or sand to protect it from the sun's ultraviolet radiation and to ensure that winds do not work the film loose in the beach area when exposed by low tide. Some of this heavier layer of gravel can be applied by the film-laying barge and some by laborers on the shore.

When the film-laying operation is completed, the film-laying barge, its laser guidance system, and the gravel slurry system will be dismantled and stored in a warehouse in the Bailey Bay area. The film-laying barge hull will be designed for disassembly into three subhulls. As much equipment as possible will be left intact on these subhulls as disassembly. The disassembly procedure will, therefore, be to remove the film-laying and gravel-distribution groups from the main hull and then to break the main hull into the three subhull sections. The components will then be loaded onto one or more flatbed trucks or trailers. The laser guidance system and the pipeline system will be disassembled and trucked away in a similar manner. The rest of the system consists of rented or leased equipment which will be returned upon completion.

Maintenance of the film-laying equipment will probably be required on an annual basis, consisting mainly of inspecting and maintaining anticorrosion agents, such as grease films. Any engines used with the system will have to be inspected, started and run briefly, and put back into the storage condition recommended by their respective manufacturers. This maintenance is not expected to require more than 1 man-month per year.

MAINTAINING THE EMPLACED FILM

Portions of the film covering the bay bottom will have to be renewed on an average of every three years. This will be required primarily because of the effect of the weather on the film, and will entail laying new film and gravel over the damaged area. Most damage probably will occur close to the shore and will result from conditions such as strong winds and high water.

Consideration has been made of the potential causes of damage to the film, both on the bay bottom and along the shore, for a 10 year time span. Of the possible causes - boating, people on the shore, decomposition of the film, and damage from the environment - in the absence of controlled laboratory experiments, only the environmental effects have been identified as being probably detrimental to the film. Of these effects, high water conditions, high wind, and bay freeze-up/thawing are expected to result in damage to approximately 16,560 square feet of film over the 10-year period considered, which is 0.046% of the total film area. This approximates to 0.014%, or 5,040 square feet of film, that will probably have to be renewed every 3 years. The potential damage sources are listed and discussed in Table H.1 and the damage estimates are summarized in Table H.2.

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TABLE H.1. POTENTIAL DAMAGE TO EMPLACED FILM

Potential Cause	Expected Effect
Boating	
• Commercial	The channel is so far away that loose barges should not pose a problem. Any such drifting carriers probably would go aground immediately after leaving the James River channel.
• Private	Buoys marking the area should keep private boats out and eliminate this potential source of damage.
Foot Traffic	Damage should not occur if people are kept away from the bank by fencing and/or warning signs.
Decomposition	Decomposition due to sunlight, temperature, wet-dry cycling, mechanical loading, chemicals, and normal film-life expectancy is estimated to be low over the 10-year period.
Environmental Effects	
• Normal Currents/Tides	No damage is expected even from drifting debris
• High Water/Flooding	Strong currents accompanying flooding could damage the film through increased water forces and by debris carried into the bay from the river and creek. It is estimated that approximately 0.01% of the total film area will be damaged during each flood.
• High Winds	High winds blowing water out of the bay could damage the plastic not completely covered with gravel. Such damage would occur approximately six times per year with a probability of damaging approximately 0.0012% of the total film area per year.
• Ice	It is expected that the bay will ice over approximately every 4 years. The damage resulting from the breakup and movement of the ice will affect approximately 0.002% of the total film area.

TABLE H.2. ESTIMATE OF FILM AREA THAT WILL BE DAMAGED DURING A 10-YEAR PERIOD

Cause of Damage	Percent of Film Damage										Total* (Sq. Ft.)
	Year of Damage										
	1	2	3	4	5	6	7	8	9	10	
Flood	--	--	0.01	--	--	0.01	--	--	0.01	--	10,800
Wind	0.0012	←							→	0.0012	4,320
Ice	--	--	--	0.002	--	--	--	0.002	--	--	1,440
Total*(sq.ft.)	432	432	4,032	1,152	432	4,032	432	1,152	4,032	432	16,560
Running Total	432	864	4,896	6,048	6,480	10,512	10,944	12,096	16,128	16,560	

* Based on 36,000,000 Square Feet Total Area

APPENDIX I

SUBMITTAL FROM ALLIED CHEMICAL, INC.
ESTIMATING QUANTITIES OF KEPONE RESIDUALS

Allied Chemical

Law Department
P.O. Box 1057R
Morristown, New Jersey 07960

November 10, 1977

Mr. Charles Terrell
Environmental Protection Agency
Marine Activities Branch WH585
401 M. Street, S.W.
Washington, DC 20460

Dear Mr. Terrel:

Herewith the inventory list of Kepone wastes held by Allied. If you need anything else, let me know.

Sincerely,

Paul [illegible] Biba

ila

Enclosure

KEPONE WASTE INVENTORY - 9/19/77

LIFE SCIENCE WASTES

Stored at Hopewell STP	Pounds		
	Gross Wt.	Net Wt.	Est. Kepone
a) 85 drums of dry Kepone powder & dirt with concentrations estimated to 80 to 85%	20,361	15,091	6,300
b) 159 drums of wet sludges from tanks containing varying amounts of Kepone, up to an estimated 40 to 50%	69,908	60,050	12,000
c) 10 drums of wet muds from tanks containing varying amounts (40 to 50%) of Kepone and traces of HCP	5,564	4,944	1,000
d) 12 drums of liquid caustic soda with trace amounts of Kepone	6,008	5,264	---
e) 99 drums of wet granular activated carbon with ca. 40 lb of Kepone removed from EPA mobile carbon adsorption unit	42,003	35,865	40
f) 35 drums of wet powdered activated carbon contaminated with est. 5 to 10 lb of Kepone	14,055	11,885	10
g) 98 drums of tank car sludge with ca. 91% water and 9% solids	37,622	25,885	1,200
h) 7 drums of contaminated work clothes, sample jars, trash, etc.	1,054	620	<10
i) 23 drums from Toledo Test Burn (1 drum of ca. 100 lb tech. Kepone inside steel container, 1 cyl. acetic acid/Kepone feedstock, 1 drum acetic acid feedstock with ca. 30 lb Kepone, wash waters, scrubber caustic water, trash, etc.	4,227	2,801	130
j) 8 drums of Broaddus Warehouse dust & dirt from October 1976	1,253	757	10
Total: Hopewell	202,055	163,162	20,700

	Pounds		
Portsmouth Naval Base	Gross Wt.	Net Wt.	Est. Kepone
96 drums of off-spec. Kepone of varying concentrations & moisture. Range of Kepone 18 to 90%	25,152	19,200	8,100
Total: Life Science Wastes	227,207	182,362	28,800

KEPONE WASTE INVENTORY - 5/8/78

ALLIED CHEMICAL CORPORATION

	Pounds			
Stored at Baltimore Site	Gross Wt.	Net Wt.	Est. Kepone	
1. Kepone Materials				
a) 162 drums of Tech. Grade	48,104	35,613	32,000	
b) 44 drums of 80%	7,687	4,712	3,770	
c) 14 drums of 25% Spec. Mix	2,408	1,371	343	
d) 285 drums of 5%	89,664	70,516	3,525	
e) 1 drum of Ant & Roach (0.125%)	279	198	<1	
f) 2 drums of Unknown Content	432	310	nil	
g) 9 drums of Compound 9160	1,549	901	nil	
h) 1 drum of Compound 9160 with 16 lb of 50% Kepone	199	127	8	
Total: 518 drums	150,322	113,748	39,646	
2. Misc. Materials Contaminated with Kepone				
a) 27 drums of cardboard, bags & fiber drums	3,185	1,511	20	(est.)
b) 20 drums of scrap metal & motors	10,147	8,907	nil	
c) 2 drums of dust collector bags	295	171	20	(est.)
d) 4 drums of Hydroscience laboratory wastes	910	644	<1	
Total: 53 drums	14,537	11,233	40	
3. Laboratory Retained Samples - Herbicides (Sumitol, Caparol, Tenaran)				
30 drums	6,061	4,129	nil	

	Pounds		
Stored at Baltimore Site	Gross Wt.	Net Wt.	Est. Kepone
4. Mirex Wastes - Paraffin Wax Contaminated with (0.03 to 4.4% Mirex)			
16 drums	3,188	2,000	20
5. Decontamination Wastes[a] Containing Arsenic			
a) 173 drums past production sludge (Kepone from washout tank - 7000 ppm arsenic)	78,997	65,247	4,600
b) 97 drums of waste from Kepone formulating area (composite 1800 ppm arsenic range to 5% to <1% to >10% Kepone)	38,648	32,636	3,000
c) 87 drums of waste from non-Kepone pesticide areas			<1
(1) 35 drums (Solution)	14,158	11,988	
(2) 31 drums (Sludge)	13,410	11,478	
(3) 21 drums (Solution & Sludge)	8,442	7,130	
Total: 357 drums	153,655	128,479	7,600
Total - Baltimore: 974 drums	327,763	259,589	47,306

(a) Arsenic content extremely variable - concentration data represents best averaged value. Lead, chromium copper and alkali salts are also present. Mercury present in sludge.

APPENDIX J

TEXT OF EMERGENCY RULE CLOSING JAMES RIVER TO SPORT AND COMMERCIAL FISHING

[illegible]
1/18/78

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COMMONWEALTH *of* VIRGINIA

Department of Health
Richmond, Va. 23219

JAMES B. KENLEY, M.D.
COMMISSIONER

January 1, 1978

EMERGENCY RULE
VIRGINIA STATE BOARD OF HEALTH

Prohibiting the Taking of Crabs and Fish from the Chesapeake Bay/James River and Its Tributaries

WHEREAS the Virginia State Board of Health is aware of conditions existing in the James River from the fall line at Richmond, to its mouth at the Chesapeake Bay and the southern most portion of the Chesapeake Bay, which constitutes a potential danger to the health and welfare of the citizens of the Commonwealth due to the unauthorized and unwarranted release or discharge of Kepone (Chlordecone) to the environment;

WHEREAS a January 1976 report of a study conducted by the National Cancer Institute implicates Kepone as a carcinogen in test animals;

WHEREAS ingestion of small amounts of Kepone may lead to accumulation and concentration in fat and body organs to levels which may be toxic to humans;

WHEREAS the long term effects of exposure to low levels of Kepone in the environment on the public health and safety have yet to be determined by scientific research;

WHEREAS the United States Food and Drug Administration pursuant to the recommendations of the US Environmental Protection Agency has revised previous action levels and established the following action levels for Kepone in the edible portions of finfish, shellfish, and crabs as acceptable levels of safety for human consumption;

	Parts per Million (ppm)
Finfish	0.3
Shellfish (clams, mussels, oysters)	0.3
Crabs	0.4

WHEREAS awareness of the above facts prompted the Virginia State Board of Health to issue an Emergency Rule on December 18, 1975 and to extend said Order on June 24, 1976 and December 28, 1976 prohibiting the taking of finfish and crabs from the James River and its tributaries as revised on February 2, 1977; to extend said Order on June, 1977 as revised on September 16, 1977;

WHEREAS samples of certain species of finfish and crabs in the James River and its tributaries and Chesapeake Bay continue to exceed the action level established by the U.S. Food and Drug Administration; (As set forth in Appendix, Part I of this Order)

WHEREAS the act of catching fish and releasing same back to the stream does not present an undue hazard to health and is not prohibited by this Emergency Rule;

WHEREAS the taking of bait minnows in the fresh water portion of the James River and its tributaries does not constitute an undue hazard to health and is not prohibited by this Emergency Rule;

WHEREAS Governor Mills E. Godwin, Jr. authorized the Virginia State Department of Health on May 20, 1976 to open the James River and its tributaries for the harvesting of channel catfish and revised on March 18, 1977 for harvesting of all catfish from the James River and its tributaries;

WHEREAS Governor Mills E. Godwin, Jr. authorized the Virginia State Department of Health on September 16, 1977 to permit the harvesting of hard crabs under the following provisions:

1/ The commercial taking of female hard crabs for processing and marketing is permitted in that portion of the James River lying seaward of the James River Bridge to the Hampton Roads Bridge-Tunnel excluding the tributaries. The mouth of the Elizabeth River is defined by a line from Craney Island to Tanner Point, the mouth of the Nansemond River and the Chuckatuck Creek by the Route 17 Bridge and the mouth of Batten Bay by a line from the north shore of the Chuckatuck to the southern most tip of Candy Island.

2/ The taking of female hard crabs for household use or in the recreational fishery is permitted in that part of the James River lying seaward of the James River Bridge excluding the tributaries.

3/ The possession or sale of peeler crabs and soft crabs is still prohibited under the Emergency Rule.

4/ The commercial and recreational taking of male hard crabs is prohibited in that portion of the Chesapeake Bay south of a line from the Buckroe Fishing Pier to Thimble Shoal Light along Thimble Shoal Channel to Chesapeake Bay Bridge Tunnel.

5/ No harvester shall have in his possession male crabs while crabbing in the James River waters and the restricted area of Chesapeake Bay. Any male crabs in possession of such harvesters shall be seized and returned to the waters.

WHEREAS Governor Mills E. Godwin, Jr., on the basis of evidence that shad and herring migrating into the James River in the early part of the season will possess acceptable Kepone residue levels, authorized the State Health Department to open the James River and its tributaries for shad and herring fishing.

WHEREAS on the basis of evidence that turtles in the James River will possess acceptable Kepone levels, the State Health Department is authorized to open the River and its tributaries for taking of turtles;

WHEREAS there is a potential for elvers (baby eels) in the James River and based on the fact that migrating elvers do not possess a digestive system for 4-5 weeks after entering the River and further on the fact that such elvers will be reared in Kepone-free ponds, the State Health Department is authorized to open the River and its tributaries for the taking of elvers.

NOW THEREFORE, acting under the authority granted to the State Board of Health in Sections 32-6 and 32-12 of the Code of Virginia (1950) as amended, the following Emergency Rule is hereby promulgated:

> Effective immediately, the taking of crabs and the catching, netting, or taking of fish from the James River and all of its tributaries from the fall line to its mouth-is-prohibited until January 1, 1979 except as indicated above for catfish, crabs, shad, herring, turtles, and elvers. The taking of male crab in the Chesapeake Bay is prohibited as indicated above. The fall line is defined by the crossing of the Fourteenth Street Bridge in the City of Richmond. The mouth of the James River is defined by the crossing of the Hampton Roads Bridge Tunnel which extends from Willoughby Spit on the South shore northwesterly to the toll plaza at the southwest end of Willard Avenue on the North shore. Excepted from this Order is that portion of the Appomattox River upstream from its fall line in Petersburg near the Seaboard Cost Line Railroad Bridge in the vicinity of Virginia State College and the Chickahominy River above Walker Dam.

Violation of this Rule is a misdemeanor as set forth in Section 32-15 of the Code of Virginia.

> Pursuant to Chapter 3.2 of Title 44 of the Code of Virginia (1950), as amended, the Governor delegates to the Virginia Marine Resources Commission and the Commission of Game and Inland Fisheries the authority to enforce this Order in the event it is violated.

The Department of Health will receive, consider, and respond to petitions by any interested person at any time for reconsideration or revision of this Emergency Rule. Such petitions should be directed to:

Commissioner of Health
Virginia State Department of Health
Room 400, James Madison Building
109 Governor Street
Richmond, Virginia 23219

It is further ordered that certified copies of this Rule be forwarded to the Governor of Virginia, the Attorney General, the State Water Control Board, the Commissioner of Game and Inland Fisheries, the Marine Resources Commission, the Virginia Institute of Marine Science, the Boards of Supervisors of Charles City, Chesterfield, Henrico, Isle of Wight, James City, New Kent, Prince George, and Surry counties, and the Mayors of the Cities of Chesapeake, Colonial Heights, Hampton, Hopewell, Newport News, Norfolk, Petersburg, Portsmouth, Richmond, Suffolk, and Williamsburg.

STATE BOARD OF HEALTH

BY:
State Health Commissioner

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SUPPORTING DATA

January 1, 1978

December 22, 1977

I. Finfish Data - Collections of finfish from the James River in 1977 continued to demonstrate Kepone levels in excess of the established action level. Resident species measured as high as 2.4 ppm Kepone in edible meat. Migratory species collected below the James River Bridge increased from a mean level of 0.083 ppm in April and May samples to an average of 0.41 ppm in June and an average of 0.76 ppm in September. The increase followed the 1976 experience where finfish collected in the same area increased from a quarterly average of 0.18 ppm to 0.92 ppm average by the end of the year. In 1976, more than 60 percent of samples exceeded the action level by the third quarter while more than 90 percent exceeded the action level in 1977.

Crab Data - Samples of male crabs in the James River and southern most portion of the Chesapeake Bay continued to demonstrate concentrations of Kepone above the action level at all stations. There were highs of 1.0 ppm in the vicinity of the James River Bridge, 1.57 ppm at the mouth of the Nansemond River, 0.57 ppm at the mouth of the Elizabeth River, 1.64 ppm on the Hampton Flats, 0.7 ppm on the Newport News Bar and 1.85 ppm in Willoughby Bay. Along Thimble Shoal channel, the average concentration found in male crabs was 0.96 ppm with a high of 1.8 ppm and 90 percent above the action level. Other male crab levels off Buckroe Beach and Ocean View were 0.64 ppm, 1.40 ppm and 1.04 ppm.

Summary - Kepone remains readily available in the River system with no anticipated changes in the coming season. All sampling for catfish, shad, and herring supported continued exception to the ban and continued monitoring showing the same seasonal experience. Seasonal increases in contamination levels to above the action level can be expected in other migratory species.

II. Emergency Rules Promulgated todate Pursuant to Sections 32-6 and 32-12 of the Code of Virginia (1950) as Amended Re: The Taking of Finfish and Shellfish from the James River and Its Tributaries

September 16, 1977	"Prohibiting the Taking of Crabs and Fish from the James River and Its Tributaries"
June 15, 1977	"Prohibiting the Taking of Crabs and Fish from the James River and Its Tributaries"
June 6, 1977	"Prohibiting the Taking of Crabs and Fish from the James River and Its Tributaries"
March 18, 1977	"Prohibiting the Taking of Crabs and Fish from the James River and Its Tributaries"
February 2, 1977	"Prohibiting the Taking of Crabs and Fish from the James River and Its Tributaries"
December 28, 1976	"Prohibiting the Taking of Crabs and Fish from the James River and Its Tributaries"
June 24, 1976	"Prohibiting the Taking of Crabs from the James River and Its Tributaries and the Taking of Fish"
June 11, 1976	"Prohibiting the Taking of Crabs from the James River and Its Tributaries and the Taking of Fish"
May 25, 1976	"Prohibiting the Taking of Crabs from the James River and Its Tributaries and the Taking of Fish"
April 14, 1976	"Prohibiting the Taking of Crabs from the James River and Its Tributaries and the Taking of Fish"
February 27, 1976	"Prohibiting the Taking of Crabs from the James River and Its Tributaries and the Taking of Fish for Human Consumption"
February 5, 1976	"Prohibiting the Taking of Crabs from the James River and Its Tributaries and the Taking of Fish for Human Consumption"
December 18, 1975	"Closing of the James River and Its Tributaries to the Taking of Fish"

III. Action Levels Established by United States Food & Drug Administration

The US Food & Drug Administration pursuant to the recommendation of the US Environmental Protection Agency has established the following action levels for Kepone in the edible portions of finfish, shellfish and crabs as acceptable levels of safety for human consumption.

		Parts per Million (ppm)
February 9, 1976	Shellfish (clams, mussells, & oysters)	0.3
		0.3
March 17, 1977	Finfish	0.4
March 22, 1976	Crabs	

January, 1976

IV. Report on Carcinogenesis Bioassay of Technical Grade (Kepone) Carcinogenesis Program, Division of Cancer Cause and Prevention, National Cancer Institute

Summary - A carcinogenesis bioassay of technical grade chlordecone (Kepone) was conducted using Osborne-Mendel rats and B6C3F1 mice. Chlordecone was administered in the diet for 80 weeks at two dose levels, with the rats sacrificed at 112 weeks weeks and the mice at 90 weeks. The starting dose levels were 15 and 30 ppm for male rats, 30 and 60 ppm for female rats, 40 ppm for male mice and 40 and 80 ppm for female mice. As these dose levels were not well tolerated, the dose levels were reduced during the course of the experiment such that the average dose levels were as follows: 8 and 24 ppm for male rats, 18 and 26 for female rats, 20 and 23 ppm for male mice and 20 and 40 ppm for female mice. Clinical signs of toxicity were observed in both species, including generalized tremors and dermatologic changes. A significant increase ($P < .05$) was found in the incidence of hepatocellular carcinomas of high dose level rats and of mice at both dose levels of chlordecone. The incidences in the high dose groups were 7% and 22% for male and female rats (compared with 0 in controls for both sexes) and 88% and 47% for male and female mice (compared with 16% for male room controls and 0 in females). For the low dose groups of mice, the incidences were 81% for males and 52% for females. In addition, the time to detection of the first hepatocellular carcinoma observed at death was shorter for treated than control mice, and in both sexes and both species, it appeared inversely related to the dose. In chlordecone-treated groups did not appear significantly different from that in controls.

V. United States Environmental Protection Agency Report to December 16, 1975 Re: Extent of Kepone Contamination of Hopewell Community and Lower James River Basin

December 16, 1975

The Health Effects Research Laboratory, United States Environmental Protection Agency, Research Triangle Park, North Carolina in a report entitled, "Preliminary Report on Kepone Levels Found in Environmental Samples from Hopewell, Virginia Area" found:

a/ 1 to 4 parts per billion of Kepone in water samples from Bailey's Creek;

b/ greater than 0.1 parts per billion of Kepone in water samples taken from the Appomattox River;

c/ 0.11 to 0.28 parts per billion of Kepone in water samples taken from the James River;

d/ fish and fish part samples contained from 0.02 to 14.4 parts per million of Kepone;

e/ oyster and clam samples taken from the fall line at Richmond to Hampton Roads contained 0.21 to 0.81 parts per million of Kepone; and

f/ sediment samples taken from Bailey's Creek, Appomattox River and James River bottoms contained 1 to 4 parts per million of Kepone.

VI. Events Leading to Closure of Life Science Products, Inc. Hopewell, Virginia

July 18, 1975

State Health Department, Bureau of Epidemiology - State Epidemiologist contacted by Center for Disease Control in Atlanta, Georgia concerning detection of Kepone in blood sample taken from an employee of Life Science Products, Inc. in Hopewell, Virginia.

July 22, 1975

State Health Department, Bureau of Industrial Hygiene - Industrial Hygiene conducted survey and atmospheric samples were taken on and off the plant site. Inspection confirmed hazardous conditions and lack of proper personnel equipment.

July 23, 1975

State Health Department, Bureaus of Epidemiology and Industrial Hygiene - State Epidemiologist and Industrial Hygienist visited Life Science Products Plant in Hopewell. Examination of ten (10) employees revealed seven (7) employees with symptoms of neurological illness, several severe enough to require hospitalization.

Inspection of the Plant revealed building, air, and ground contamination with Kepone and its precursors (compounds used to make Kepone), inadequate personnel protection precautions, and unsafe operating conditions.

July 24, 1975

State Health Department, Bureaus of Epidemiology, Industrial Hygiene, Division of Engineering, and Attorney General's Office meeting with officials of Life Science Products, Inc.

Acting under the authority granted to the State Board of Health in Section 32-12 of the Code of Virginia, special order was prepared requiring the Company to cease production of new Kepone and begin immediately to clean up the site under carefully supervised conditions.

Plant management agreed to comply voluntarily with all the conditions and the order was not issued, but was held in the event of non-compliance.

The owner submitted a timetable for cleanup and disposal which was acceptable to the Health Department.

APPENDIX K

DETAILS OF ECOLOGICAL COMMUNITIES IN THE JAMES RIVER

APPENDIX K

DETAILS OF ECOLOGICAL COMMUNITIES IN THE JAMES RIVER

BIOTIC COMMUNITIES

Seasonal Dominance of Fish

Seasonal dominance of fish in the tidal James River has been studied during the years 1967 to 1971 and in February and June of 1972 by VIMS scientists (VIMS, 1973; Wass and Wright, 1969). Relatively few species have an entirely estuarine existence throughout the year.

The hogchokers are the most ubiquitous estuarine fish from the poly-oligohaline to the lower fresh-water zones at all seasons. White perch are the dominant species during the winter and spring, while the bay anchovy and the spot are dominant in the summer and fall. Most of the marine and estuarine species use the estuarine zones (poly-oligohaline) as nursery and feeding grounds. Lower salinity (oligohaline) and tidal fresh-water areas mainly serve as spawning and nursery grounds for anadromous and fresh-water fish. The polyhaline zone exhibits more variation in species dominance, whereas the fresh-water zone has a more stable fish fauna the year round.

Winter. During the winter the higher salinity zones are dominated by the hogchoker and anadromous fish, e.g., herrings (blueback herring and alewife) as well as white perch (Figure K.1). The bay anchovies and the Atlantic croaker are abundant in the lower portions of the poly-meshohaline areas. The freshwater species, channel and white catfish, penetrate downstream to the oligohaline zone and are among the dominants in the area. The tidal freshwater zones are almost exclusively dominated by freshwater species, mainly catfish (channel, white, and brown bullhead) and spottail shiner.

Spring. The hogchokers are the most dominant fish in the spring (Figure K.2). The marine fish, such as weakfish, spot, and spotted hake, enter the estuary and become dominants in the poly-mesohaline zones. The white perch dominate the oligohaline zone along with the channel and white catfish. The tidal fresh-water portion above RM 36 was not documented during the 1967-1971 study period. However, it is known that, of the anadromous fish, the alosin group and striped bass as well as white perch move into the fresh-water zone to spawn and remain there throughout the spring.

Summer. In the summer the poly-mesohaline zones are populated predominately by marine species: weakfish, spot, silver perch, and Atlantic croaker (Figure K.3). The oligohaline and tidal fresh-water areas are more populated with estuarine (bay anchovy, hogchoker), anadromous (alewife), resident (white perch) and fresh-water species (channel catfish). The spot and hogchoker are dominants in all salinity regimes. The fresh-water zone is prime nursery ground for all new hatched juveniles during the summer.

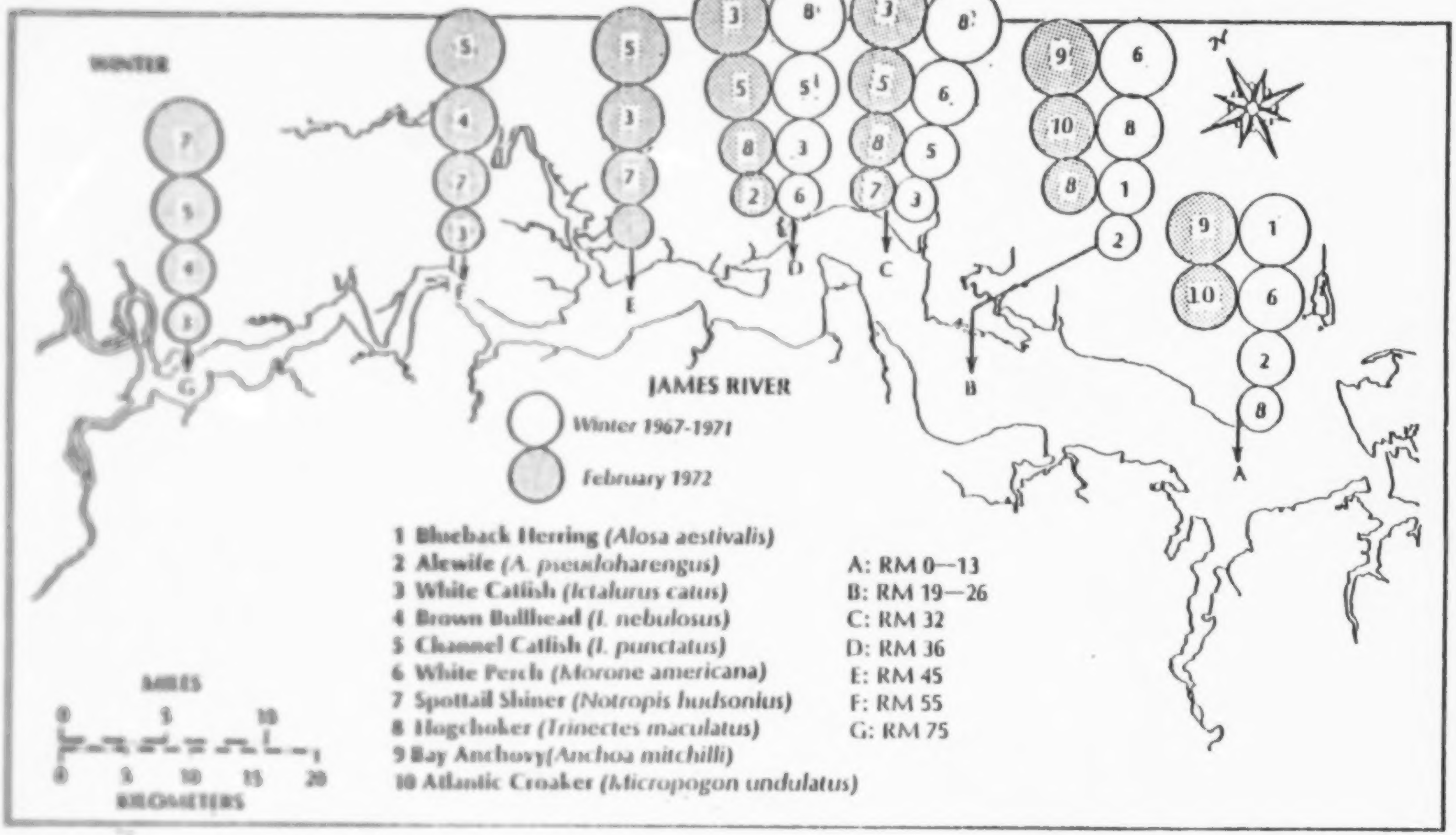

WINTER
JAMES RIVER
Winter 1967-1971
February 1972
N
A
B
C
D
E
F
G
1 Blueback Herring (Alosa aestivalis)
2 Alewife (A. pseudoharengus)
3 White Catfish (Ictalurus catus)
4 Brown Bullhead (I. nebulosus)
5 Channel Catfish (I. punctatus)
6 White Perch (Morone americana)
7 Spottail Shiner (Notropis hudsonius)
8 Hogchoker (Trinectes maculatus)
9 Bay Anchovy (Anchoa mitchilli)
10 Atlantic Croaker (Micropogon undulatus)
A: RM 0—13
B: RM 19—26
C: RM 32
D: RM 36
E: RM 45
F: RM 55
G: RM 75
MILES
0 5 10
0 5 10 15 20
KILOMETERS

FIGURE K.1. Seasonal Dominance of Fish During the Winter. The larger the circle, the more dominant the species (VIMS, 1973).

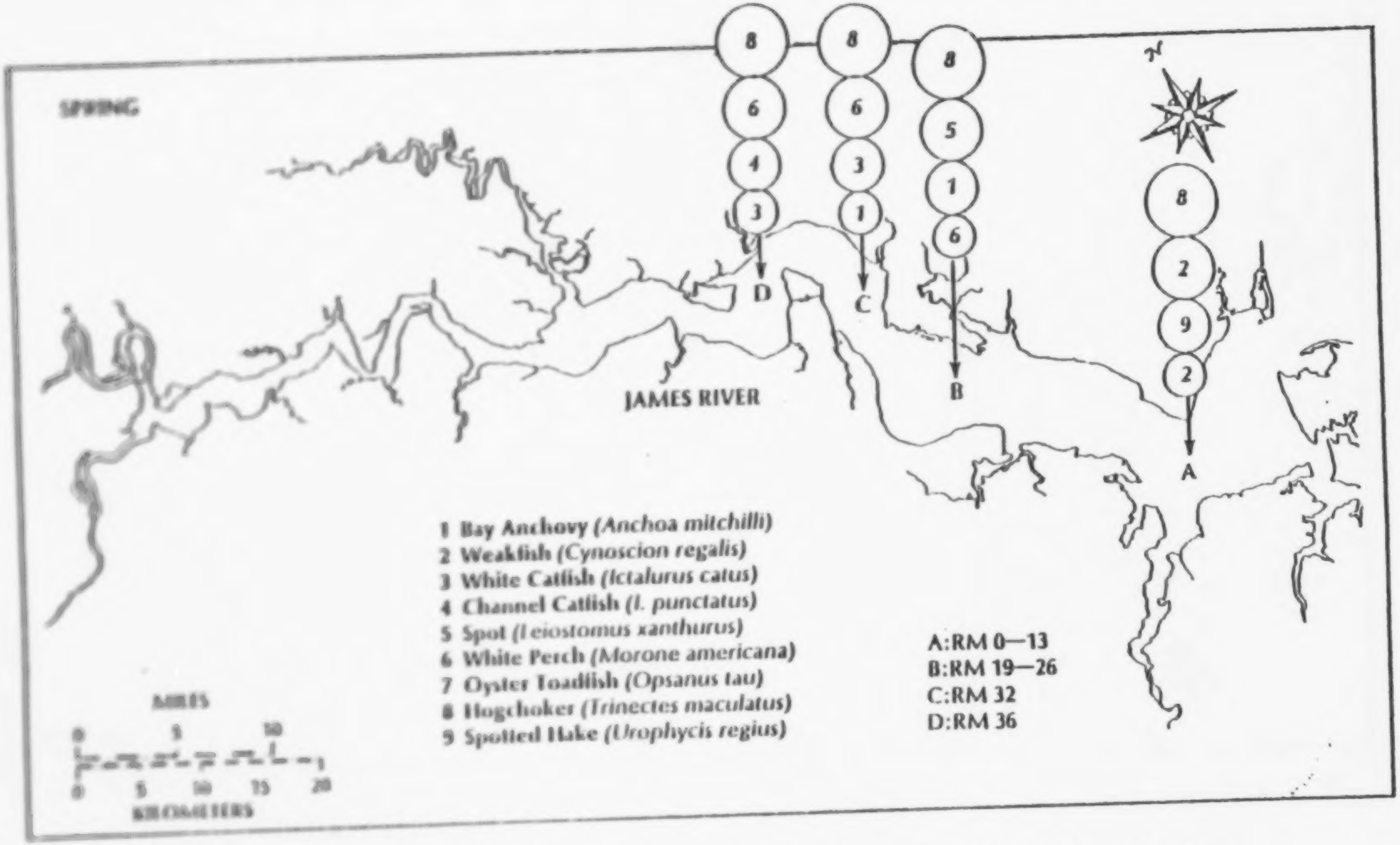

SPRING
JAMES RIVER
N
8
6
4
3
D
8
6
3
1
C
8
5
1
6
B
8
2
9
2
A
1 Bay Anchovy (Anchoa mitchilli)
2 Weakfish (Cynoscion regalis)
3 White Catfish (Ictalurus catus)
4 Channel Catfish (I. punctatus)
5 Spot (Leiostomus xanthurus)
6 White Perch (Morone americana)
7 Oyster Toadfish (Opsanus tau)
8 Hogchoker (Trinectes maculatus)
9 Spotted Hake (Urophycis regius)
A:RM 0—13
B:RM 19—26
C:RM 32
D:RM 36
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE K.2. Seasonal Dominance of Fish During the Spring. The larger the circle, the more dominant the species (Vims, 1973).

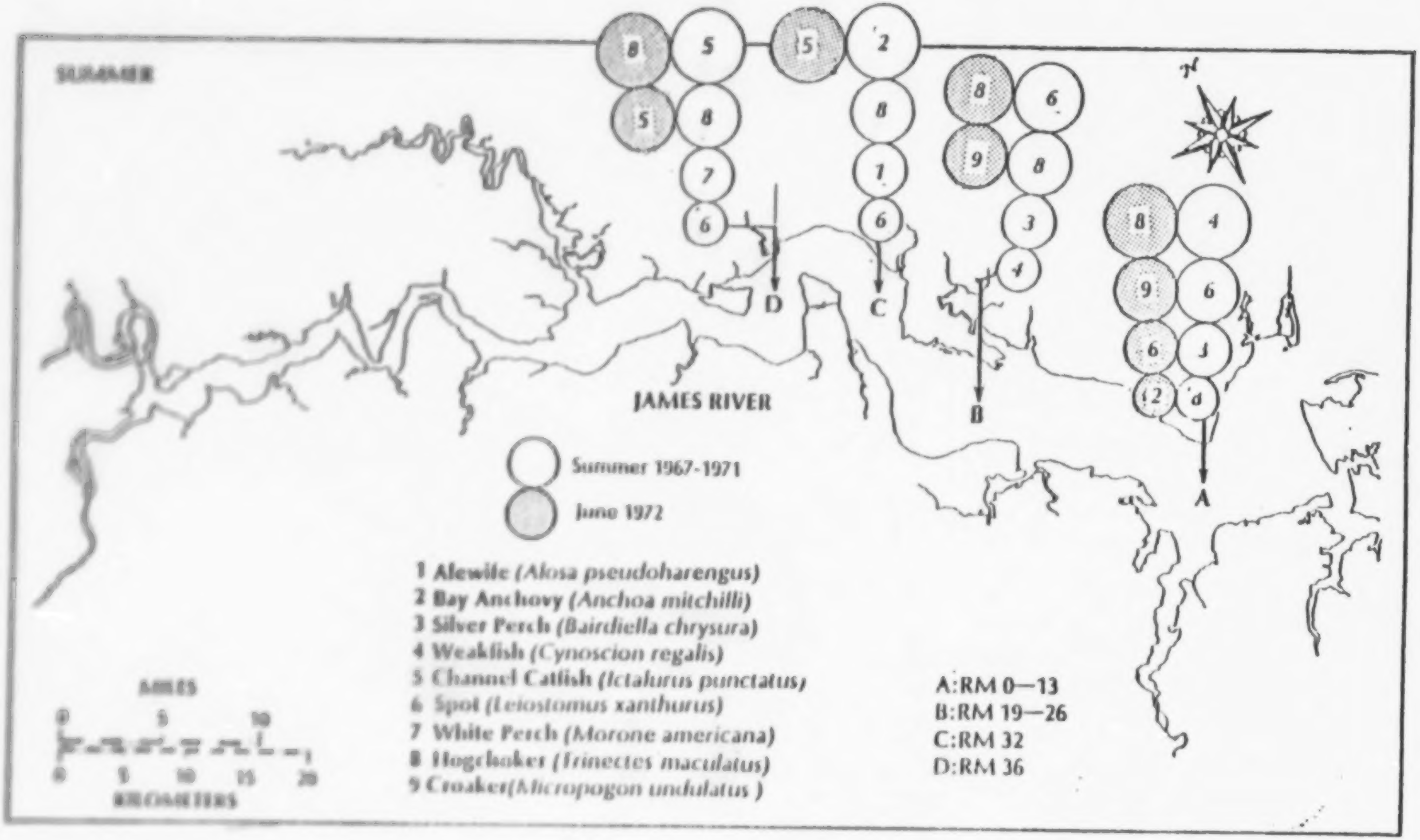

SUMMER
8
5
5
8
7
6
15
2
8
1
6
8
6
9
8
3
4
8
4
9
6
6
1
12
8
D
C
B
A
JAMES RIVER
Summer 1967-1971
June 1972
1 Alewife (Alosa pseudoharengus)
2 Bay Anchovy (Anchoa mitchilli)
3 Silver Perch (Bairdiella chrysura)
4 Weakfish (Cynoscion regalis)
5 Channel Catfish (Ictalurus punctatus)
6 Spot (Leiostomus xanthurus)
7 White Perch (Morone americana)
8 Hogchoker (Trinectes maculatus)
9 Croaker(Micropogon undulatus)
A:RM 0—13
B:RM 19—26
C:RM 32
D:RM 36
MILES
0
5
10
0
5
10
15
20
KILOMETERS
N

FIGURE K.3. Seasonal Dominance of Fish During the Summer. The larger the circle, the more dominant the species (VIMS, 1973).

Fall. As the fall season approaches, most of the marine fish move downstream and later enter the ocean for wintering (Figure K.4). Anadromous fish also concentrate in the lower estuaries. The croaker becomes dominant in the oligohaline zone and the catfish are abundant in the fresh/salt-water interfaces. Again the hogchoker dominates through the entire estuary. At this time most juvenile fish have moved to the more saline part of the estuary from their spawning and nursery grounds in the fresh-water zone.

Freshwater Fish

Channel Catfish (*Ictalurus punctatus*)
Brown Bullhead (*Ictalurus nebulosus*)
White Catfish (*Ictalurus catus*)

Three major catfish species occur in the James River: channel catfish, white catfish, and brown bullhead. Of these, the channel catfish is the most numerous and most widely distributed with its major concentration areas being in the RM 30-80 area (Figure K.5). The brown bullhead is also abundant, mainly in the areas between RM 55 and RM 66 and in the Turkey Island oxbow area. The white catfish is found mostly in the RM 40-60 range but is the least numerous among the catfish group.

Channel catfish spawn during late May through early July. Brown bullhead spawn from April to June. Both fish mainly utilize the oxbow habitats as a nursery ground (VIMS, 1973; Lanier, 1971; Menzel, 1943).

Biomass projections developed by VIMS yield the following estimates:

Species	Winter James River (kg)	Summer (kg) River Mile				
		0-15	16-25	26-35	36-45	Total 0-45
White Catfish	3.3×10^4	0	0	2.9×10^6	4.0×10^5	3.3×10^6
Channel Catfish	3.3×10^5	0	0	1.5×10^5	8.8×10^6	9.0×10^6
Brown Bullhead	3.8×10^4	NA	NA	NA	NA	NA

Estuarine Fish

Hogchoker (*Trinectes maculatus*)
Bay Anchovy (*Anchoa mitchilli*)

These two fish are not commercially harvested in the James River but are of ecological importance due to their numerical dominance and ubiquitous distribution throughout the estuary and fresh-water zone up to RM 80.

The hogchoker is the most ubiquitous fish in the James River. This bottom-feeding flatfish is found in all salinity zones at all seasons. Spawning occurs from May through September with a peak in July to August. Spawning grounds are in the meso-to polyhaline zone where salinities are greater than

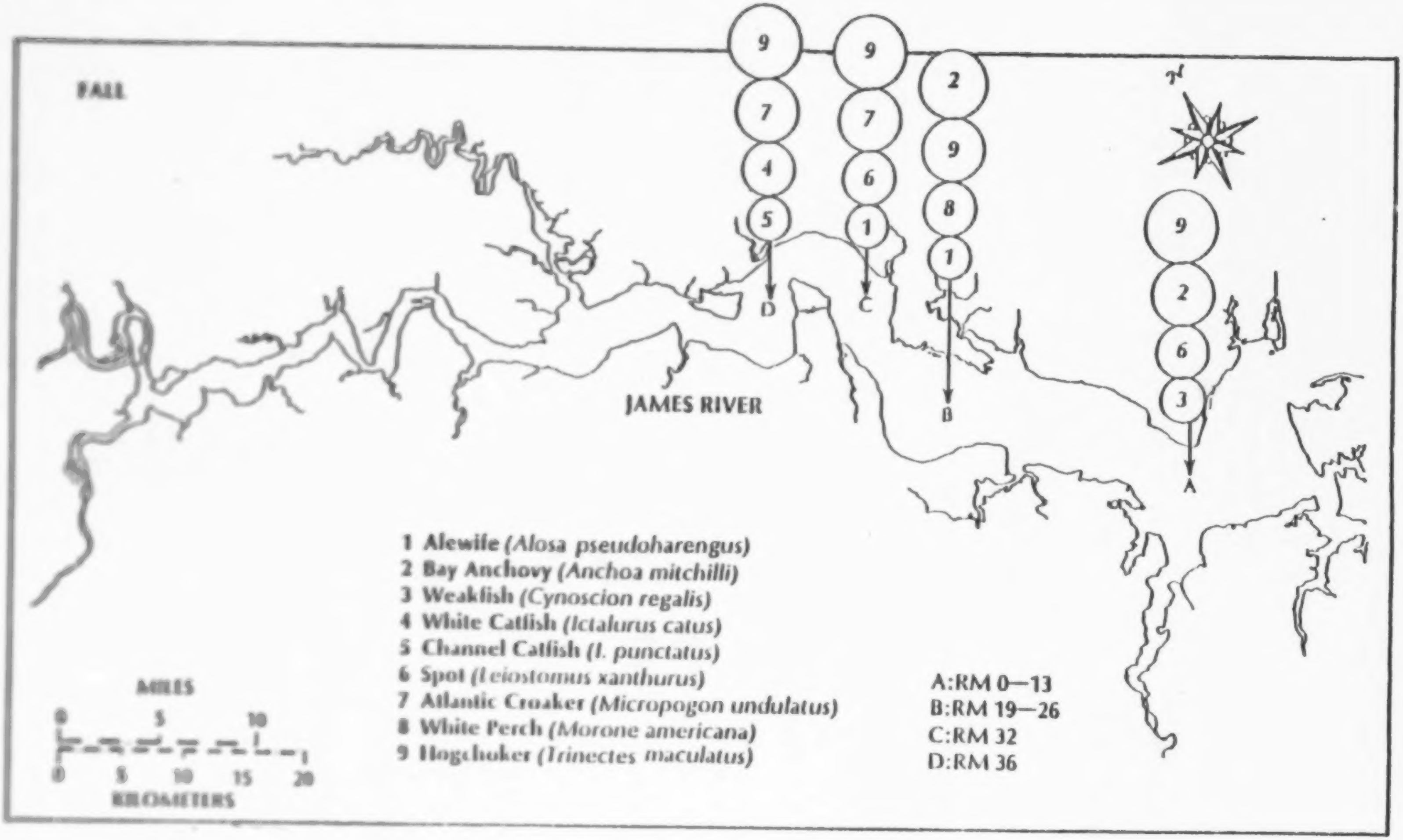

FALL
9
7
4
5
D
9
7
6
1
C
2
9
8
1
B
9
2
6
3
A
JAMES RIVER
1 Alewife (Alosa pseudoharengus)
2 Bay Anchovy (Anchoa mitchilli)
3 Weakfish (Cynoscion regalis)
4 White Catfish (Ictalurus catus)
5 Channel Catfish (I. punctatus)
6 Spot (Leiostomus xanthurus)
7 Atlantic Croaker (Micropogon undulatus)
8 White Perch (Morone americana)
9 Hogchoker (Trinectes maculatus)
A:RM 0—13
B:RM 19—26
C:RM 32
D:RM 36
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE K.4. Seasonal Dominance of Fish During the Fall. The larger the circle, the more dominant the species (VIMS, 1973).

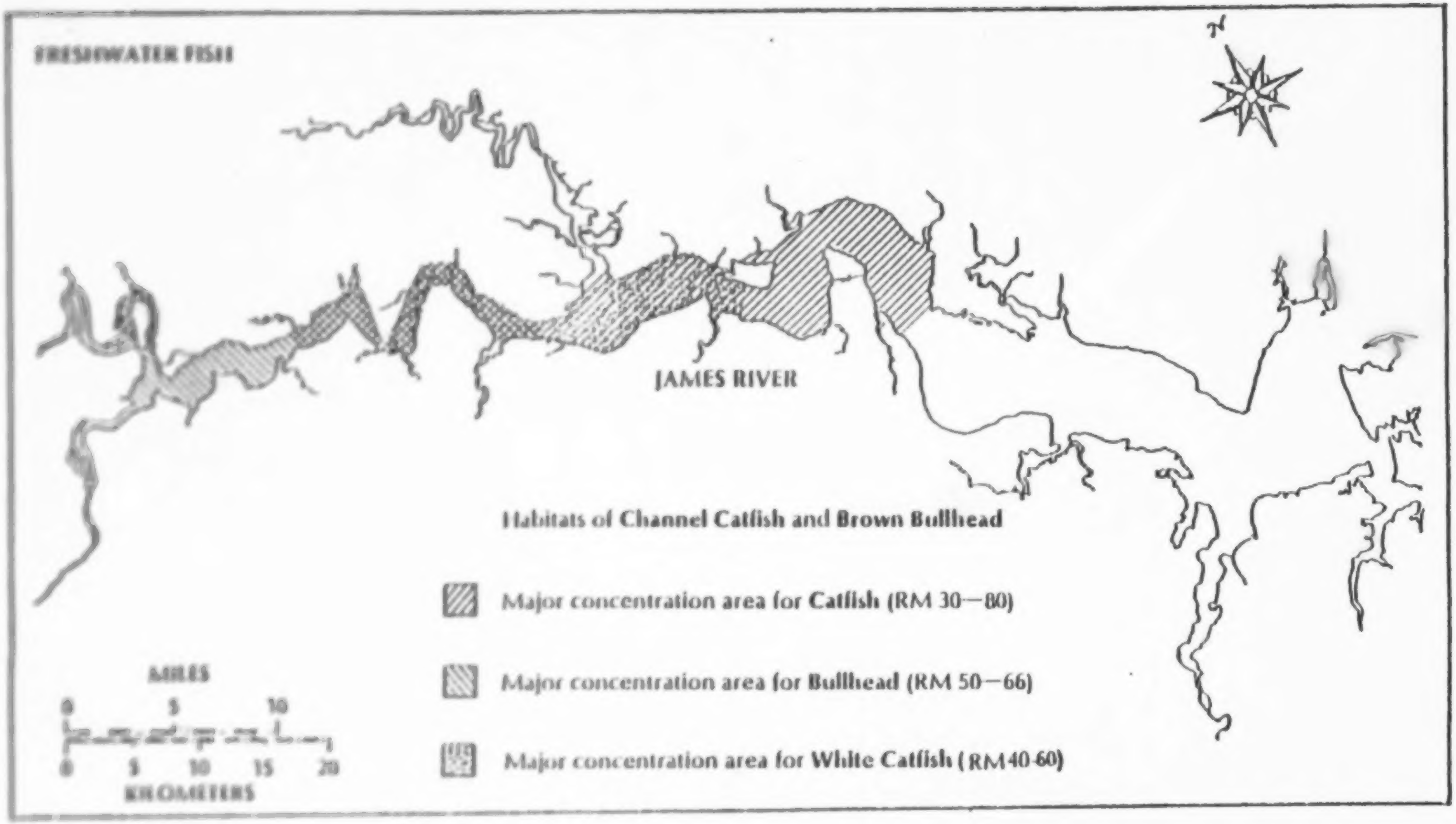

FRESHWATER FISH
N
JAMES RIVER
Habitats of Channel Catfish and Brown Bullhead
▨ Major concentration area for Catfish (RM 30—80)
▨ Major concentration area for Bullhead (RM 50—66)
▩ Major concentration area for White Catfish (RM40-60)
MILES
0 5 10
0 5 10 15 20
KILOMETERS

FIGURE E.5. Distribution of Major Freshwater Fish (Channel Catfish, Brown Bullhead and White Catfish) (VIMS, 1973; Engineering-Science Co., 1974)

9 ppth. The juveniles are distributed from mesohaline to fresh water with major concentrations in the oligohaline zone. Young hogchokers remain in the nursery areas in the first year and descend farther downstream with the following year migration (Figure K.6). The hogchokers spend their winter in the channel at oligo- to polyhaline areas (VIMS, 1973; Van Engel and Joseph, 1968).

The bay anchovy is one of the most numerous fish and an important forage food for many fish in the James River. They are small but grow rapidly and move in large schools. Spawning occurs between April and September (peaking in July-August) mainly in the polyhaline water with a salinity of 13-15 ppth. Juvenile anchovies are widely distributed from meso- to fresh water but tend to congregate in the areas of the salt/fresh-water interface (oligohaline zone). Adult anchovies are randomly distributed throughout the estuary from oligo- to mesohaline in the warm season (spring to fall). They stay in deeper waters and the lower portion of the polyhaline zones in winter (VIMS, 1973; Dovel et al., 1969; Van Engel and Joseph, 1968).

Biomass projections developed by VIMS yield the following estimates:

Species	Winter James River (kg)	Summer (kg) River Mile 0-15	16-25	26-35	36-45	Total 0-45
Hogchoker	5.7×10^4	3.6×10^6	8.2×10^5	1.0×10^6	7.0×10^5	6.1×10
Bay Anchovy	2.8×10^4	1.5×10^7	3.4×10^6	3.1×10^5	2.6×10^5	1.9×10^7

Anadromous Fish

Alewife (*Alosa psuedoharengus*)
Blueback Herring (*Alosa aestivalis*)
American Shad (*Alosa sapidissima*

The alosin fish are widely distributed throughout the Chesapeake Bay and its major rivers, including the James River (Figure K.7). All of these fish spawn in the tidal fresh-water sections of the river between Jamestown Island (RM 42) and Richmond (RM 10) but primarily above the RM 64 (VIMS, 1973).

Spawning of the alewife takes place from mid-March to mid-May when water temperatures range from 11to 23°C. Blueback herring spawn from mid-April through late May where thetemperature is above 14°C. The American shad spawns from early April tolate May. Adult herrings move down to the lower estuary after spawning andremain there throughout the summer. Juveniles remain in the river betwee RM 35 and RM 80, but the majority of them appear to stay in the areas betwen RM 60 and RM 80. Young alosins move out of the estuary in November-Decembr. (VIMS, 1973).

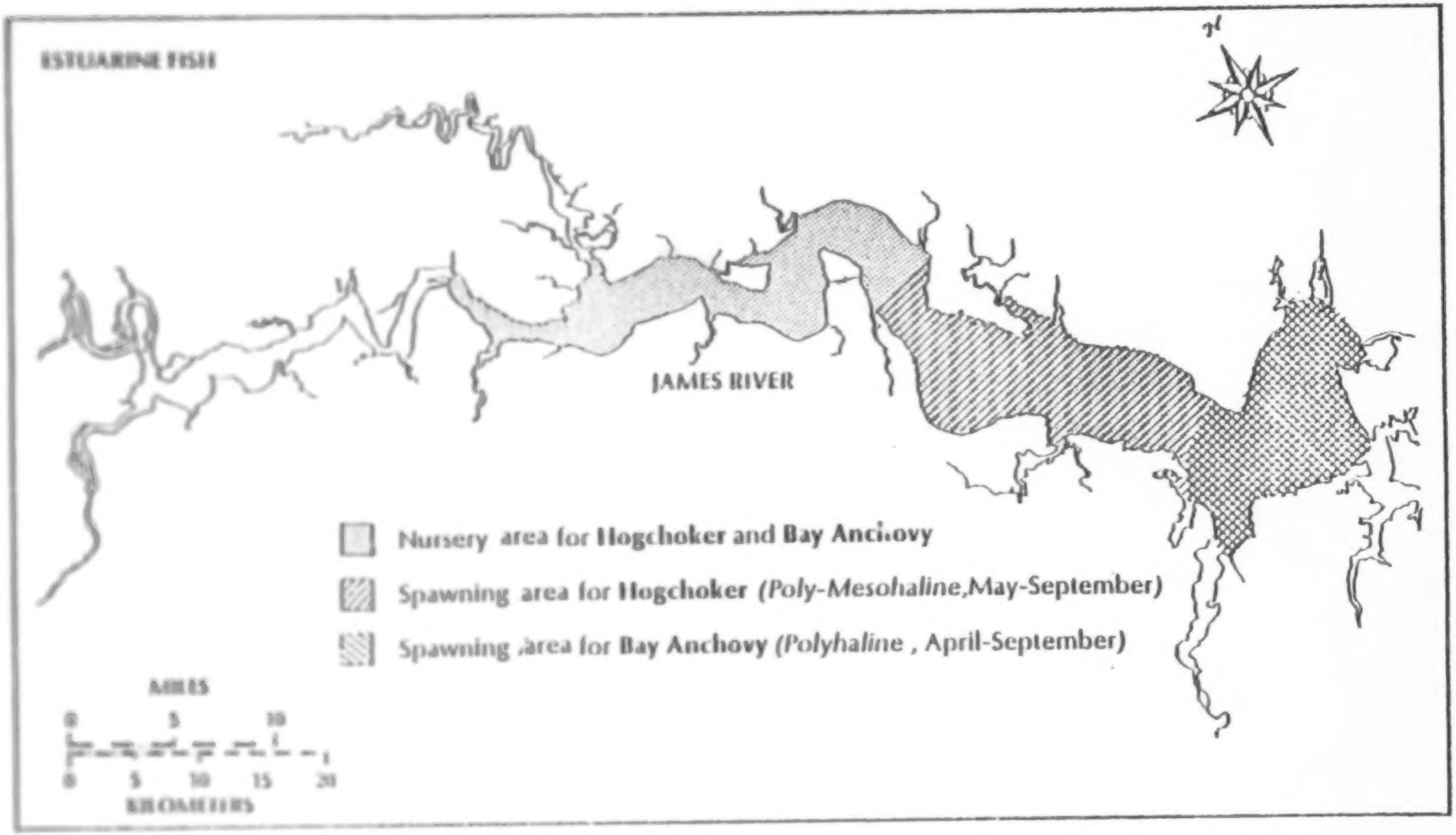

ESTUARINE FISH
N
JAMES RIVER
▢ Nursery area for Hogchoker and Bay Anchovy
▨ Spawning area for Hogchoker (Poly-Mesohaline,May-September)
▨ Spawning area for Bay Anchovy (Polyhaline , April-September)
MILES
0 5 10
0 5 10 15 20
KILOMETERS

FIGURE K.6. Spawning and Nursery Areas for the Estuarine Fish, Hogchoker and Bay Anchovy (Van Engel and Joseph, 1968; VIMS 1973)

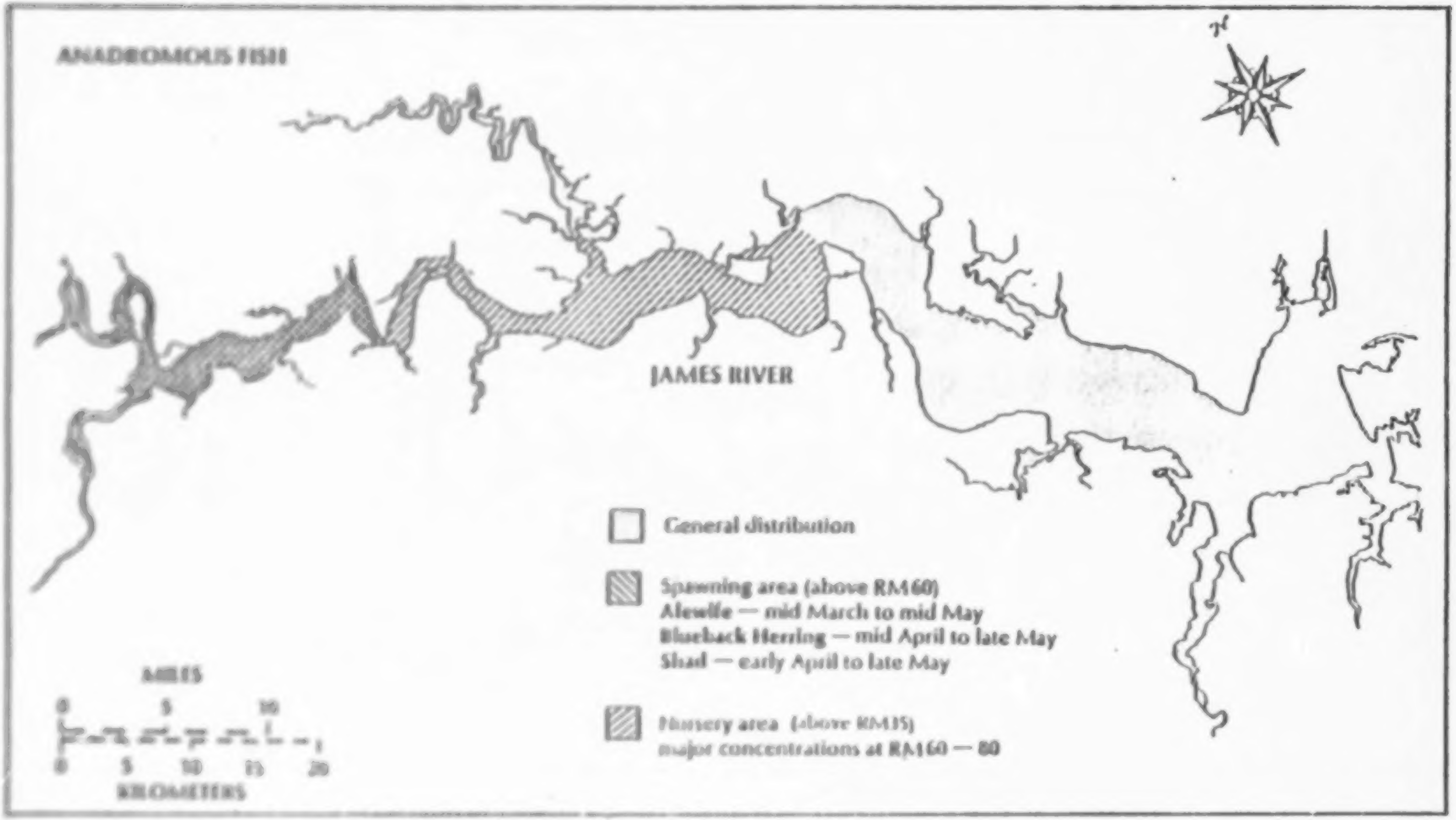

ANADROMOUS FISH
N
JAMES RIVER
▢ General distribution
▧ Spawning area (above RM60)
Alewife — mid March to mid May
Blueback Herring — mid April to late May
Shad — early April to late May
▨ Nursery area (above RM35)
major concentrations at RM60 — 80
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE K.7. Distribution of the Herrings

Studies from 1969 through 1975 show that more than 93% of the juvenile alosins caught are blueback herring, approximately 4% are alewife, and less than 3% are American shad (Hoagmen et al., 1973; Hoagman and Kriete, 1975). Populations of juvenile alosins in the James River have declined considerably during the past several years. Since 1970 the estimates of year-class alewife populations were reduced from 118 to 4 million and shad from 30 to 1 million in 1975. The populations of blueback herring decreased from 1,633 million in 1970 to 62 million in 1974, but increased to 1,908 million 1975. The abrupt increase of year-class bluebacks (30-fold increase) in 1975 from the previous year has not been explained (Hoagman and Kriete, 1975).

Biomass projections developed by VIMS yield the following estimates:

Species	Winter James River (kg)	Summer (kg) River Mile 0-15	16-25	26-35	36-45	Total 0-45
Alewife	2.3×10^4	NA	NA	NA	NA	NA
Bluback Herring	4.3×10^3	0	2.8×10^4	2.8×10^4	2.8×10^3	5.9×10^4
American Shad	4.6×10^3	NA	NA	NA	NA	NA

Striped Based (*Morone saxatilis*)
White Perch (*Morone americana*) - White perch are resident in the James rather than anadromous.

The striped bass is one of the most important commerical and sport anadromous fish in the Chesapeake Bay area. The bass is highly tolerant to varying salinities and widely distributed throughout the Bay and up to the tidal fresh-water section of the rivers.

In the James River, the striped bass spawn during April-June in the area between Jamestown Island (RM 42) and Turkey Island (RM 80) with the major concentrations occurring around RM 60-72 zones (Figure K.8). Favorable spawning grounds are where the river flows rapidly. After spawning, most adults move downstream but remain in the river throughout the summer, actively feeding along the shoal areas (VIMS, 1973).

Juveniles are mainly concentrated at RM 36-53 and move gradually downstream as they grow (VIMS, 1973). Both the adult and young striped bass winter in deeper waters (greater than 9 m or 30 ft) of the River and Bay (Lippson, 1973). It is known that the striped bass return to the same river in the following year and thus the James River fish are rarely mixed with those from other rivers that flow into the Chesapeake Bay (Massmann and Pacheco, 1961).

The white perch is primarily estuarine with greatest abundance occurring in tidal waters of 3-10 ppth salinities. Though resident, they are also considered as semi-anadromous since they migrate to the tidal fresh water for

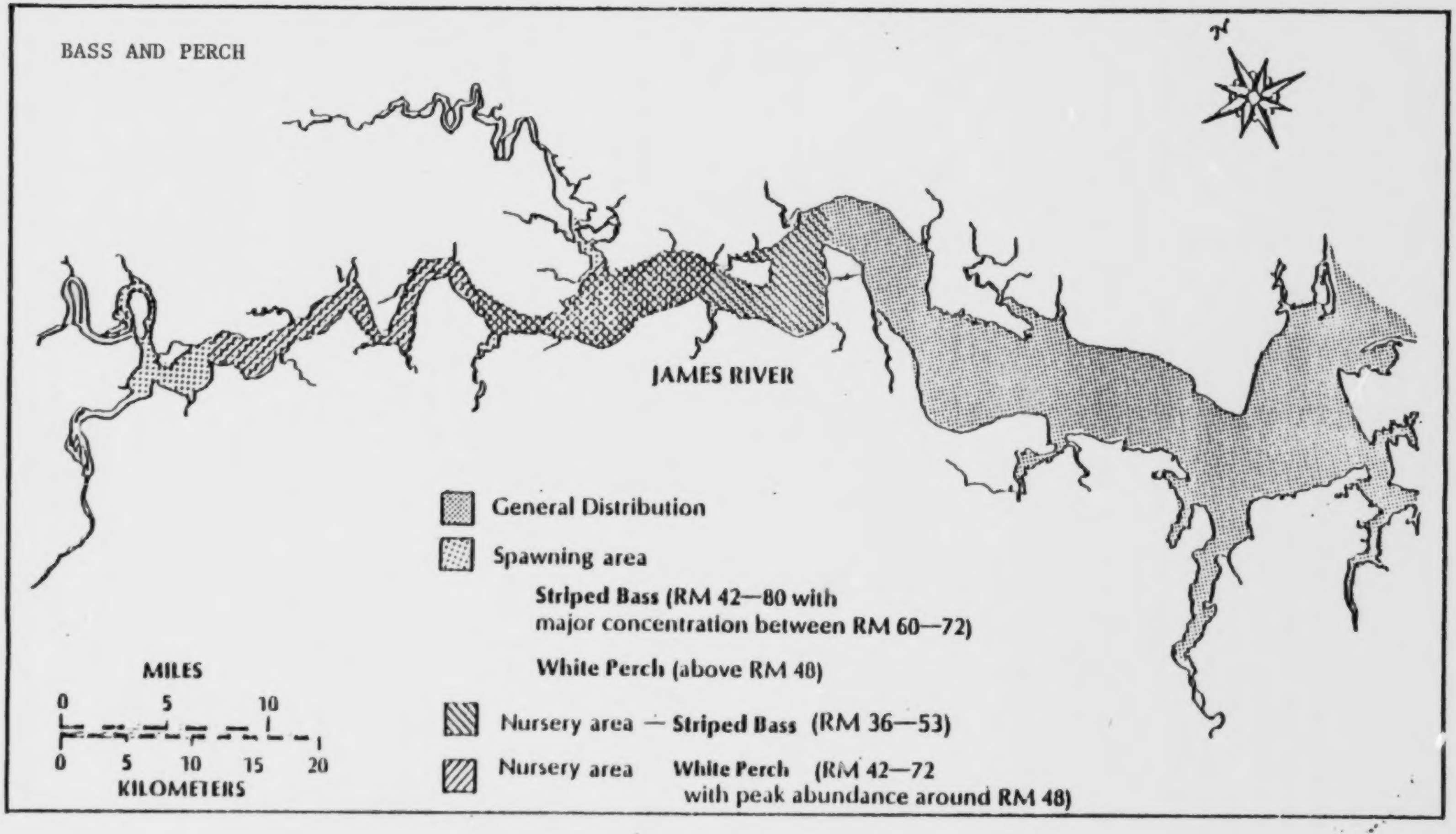

BASS AND PERCH
N
JAMES RIVER
General Distribution
Spawning area
Striped Bass (RM 42—80 with major concentration between RM 60—72)
White Perch (above RM 48)
Nursery area — Striped Bass (RM 36—53)
Nursery area White Perch (RM 42—72 with peak abundance around RM 48)
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE K.8. Distribution of the Striped Bass and White Perch (Mansueti, 1964; Lippson, 1973; Massman and Pacheco, 1961; VIMS, 1973)

spawning (Mansueti, 1964; St. Pierre and Hoagman, 1975). The white perch spawn in mid-April through mid-May when water temperatures are between 10 and 15°C (Figure K.8). They appear to spawn in the Chickahominy River and fresh-water section of the James above RM 48. Juvenile white perches are widely distributed in the areas between RM 42 and 72 (VIMS, 1973).

Migrating patterns of the white perch are similar to those of striped bass. Adults remain in the tidal fresh water until early June then move downstream. Juveniles spend their first summer and fall in the shallow beach areas. Both move into the waters deeper then 30 to 40 ft for wintering. Recently, white perch abundance has been drastically reduced to nearly 1 to 3% of its normal population since a massive fish kill in the early 1970's (St. Pierre and Hoagman, 1975); the exact cause of which was not determined.

Biomass projections developed by VIMS yield the following estimates:

Species	Winter James River (kg)	Summer (kg) River Mile 0-15	16-25	26-35	36-45	Total 0-45
Striped Bass	4.0×10^2	0	2.8×10^4	2.7×10^4	0	5.5×10^4
White Perch	4.5×10^3	0	1.3×10^5	2.5×10^5	1.7×10^6	2.1×10^6

Marine Fish

Spot (*Leiostomus xanthurus*)
Croaker (*Micropogon undulatus*)
Weakfish (*Cynoscion regalis*)
Silver Perch (*Bairdiella chrysura*)

There are more than 18 species of marine fish occurring in the fresh and brackish waters of Virginia including the James River (Massmann, 1954). The above four species, all of the family Sciaenidae (drums), are the dominant marine fish in the James River estuary. All enter the Chesapeake Bay and its estuarine rivers during the warmer months and return to the sea in winter. They spawn along the coasts of the ocean and the bay. Young fish spend at least their first year in the estuaries and gradually descend toward deeper and more saline waters as they mature.

Spot are the most abundant among this group. They spawn from November to January. Young spot enter the James estuary up to fresh water (RM 60), but most juveniles are found in the shallow waters of meso- and polyhaline zones (Figure K.9). Spot are the dominant fish in these areas throughout the summer months (VIMS, 1973; Van Engel and Joseph, 1968).

Atlantic croakers enter the estuarine waters in early spring and swim as far as the tidal fresh-water zone (RM 60). Abundance of the croaker is much less than that of the spot and it fluctuates considerably depending largely

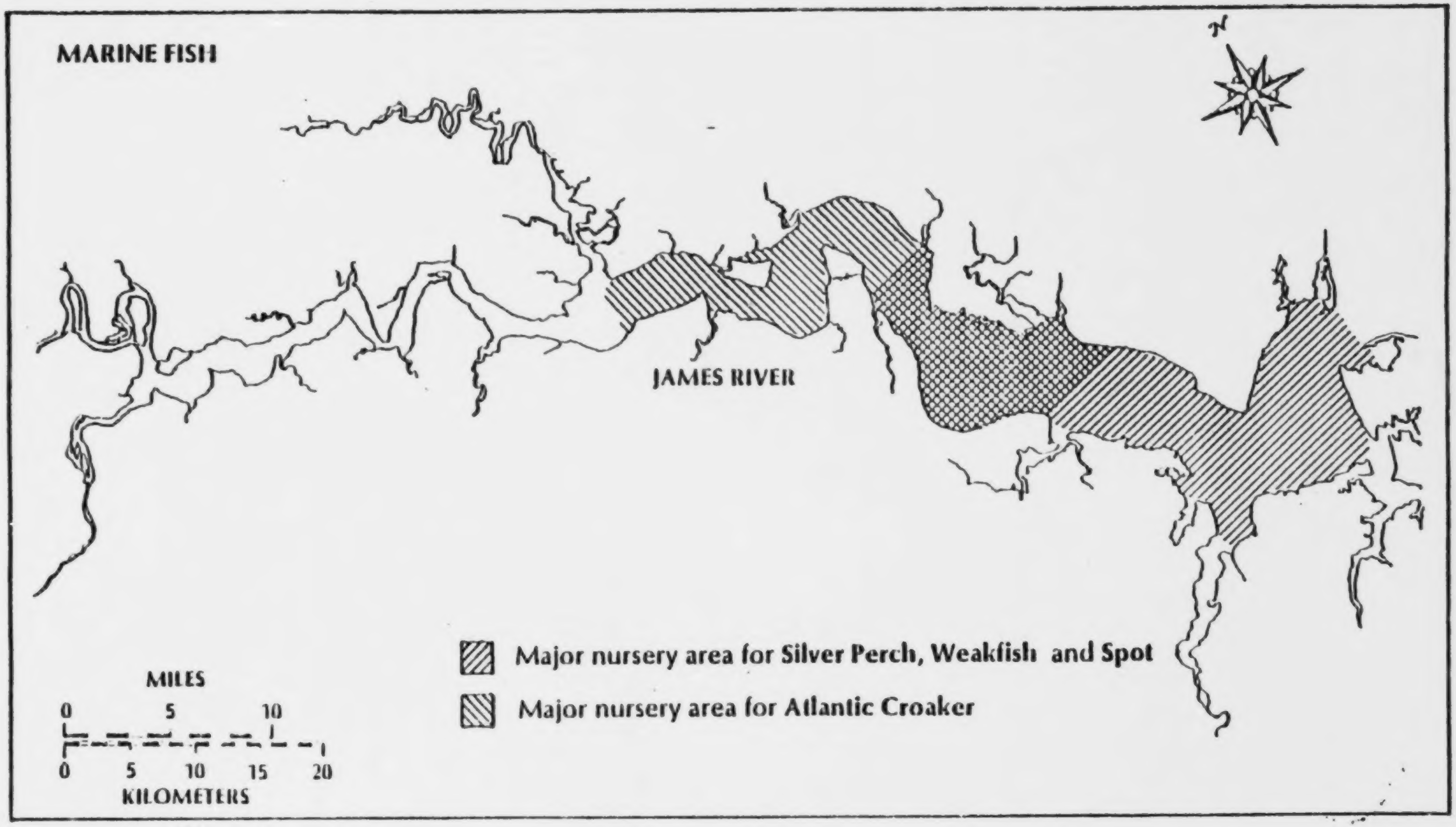

MARINE FISH
N
JAMES RIVER
▨ Major nursery area for Silver Perch, Weakfish and Spot
▧ Major nursery area for Atlantic Croaker
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE K.9. Distribution of Nursery Areas for the Spot, Weakfish and Silver Perch (VIMS, 1973)

upon water temperatures. Adult croakers leave the estuarine waters for the ocean as the spawning season approaches. Spawning season extends from early fall to winter (Haven, 1957; Van Engel and Joseph, 1968). Juveniles begin to migrate into the river in late summer and early winter. Young croakers are the most abundant in the fall and winter at meso- to oligohaline zones at RM 18-48 (VIMS, 1973). Striped bass prey upon young croakers (5-10 cm).

Weakfish (or seatrout) spawn from May to August. Young weakfish move into the Chesapeake Bay and the James River oligohaline zone in July and August. They slowly retreat to polyhaline water in October. Adult weakfish leave the Bay in fall and are absent in winter (VIMS, 1973).

Silver perch are the dominant fish in the poly- to mesohaline zones during the summer. They occasionally occur in the fresh-water area (RM 50). They spawn from May to August in the Bay and the polyhaline zones of the James River. Most juveniles are found in the poly- and mesohaline zones up to RM 30. Like other marine fish, the silver perch retreat from the bay in the fall and are absent in winter (VIMS, 1973).

Biomass projections developed by VIMS yield the following estimates:

Species	Winter James River (kg)	Summer (kg) River Mile 0-15	16-25	26-35	36-45	Total 0-45
Spot	5.3×10^4	2.1×10^7	1.3×10^7	1.2×10^7	1.8×10^7	6.4×10^7
Atlantic Croaker	1.4×10^5	1.5×10^7	4.2×10^6	1.4×10^6	4.9×10^6	2.6×10^7
Weakfish	NA	NA	NA	NA	NA	NA
Silver Perch	NA	NA	NA	NA	NA	NA

Dominant Benthic Invertebrates

There are distinct differences in the faunal systems between different salinity zones along the James River. The lack of diverse habitats and high pollution loadings render the tidal fresh-water zone less diverse in species composition. There is a constant shifting of fresh-water and estuarine organisms in the oligohaline zone. The major deposition of alluvial sediment load and mixing of fresh and saline waters provide the greatest turbidity and make this zone the harshest environment in the entire James estuary (Diaz, 1977). The lower portion of the James River has the most complex community structure of all. The relatively constant high salinities and the largest variety of sediment types existing in the mesopolyhaline zone support a much more diversified fauna.

Of the 29 benthic invertebrate species considered to be dominant, only 7 species are confined to fresh water. Eighteen species are distributed in the saline waters (poly-oligohaline) and the remainder are dispersed to oligo-fresh-water zones. The distribution of dominant benthic invertebrates in the James River during the summer and fall of 1972 is shown in Figures K.10 and K.11 (Diaz, 1977).

At that time the tidal fresh-water zone was dominated by three major groups during the summer and fall (Diaz, 1977): oligochaete worms (*Limnodrilus* spp. and *Ilyodrilus templetoni*), dipteran larvae (*Coelotanypus scapularis*), and the Asian bivalve (*Corbicula manilensis*). The wedge clam (*Rangia cuneata*) was dominant in the lower portion of the fresh-water zone (Cain et al., 1972). The oligohaline area was also dominated by three major groups: polychaete larvae (*Scolecolepides viridis*), amphipods (*Gammarus daiberi*) (Diaz, 1977) and the wedge clam (*Rangia cuneata*). An estuarine oligochaete (*Peloscolex heterochaetus*) was dominant around Jamestown Island and off Mulberry Island area during fall.

More complex patterns of dominance were observed in the mesohaline zone. Nearly 12 out of 70 species were found to dominate these waters (Diaz, 1977). The polychaete worms and amphipods were dominant throughout the area in both seasons. *Heteromastus filiformis*, *Nereis succinea* and *Polydora ligni* were the representative polychaetes, while *Leptocheirus plumulosus* and *Corophium lacustre* were the prominent amphipods. The *Corophium lacustre* was extremely abundant reaching more than 10,000 organisms per m^2 around RM 17 off the mouth of Warwick River during the summer of 1972. The marine barnacle (*Balanus improvisus*), a dominant, along with a mussel (*Branchiodontes recurvus*), appeared in the area between RM 17 and RM 25. An oligochaete (*Peloscolex heterochaetus*), generally restricted to lower salinity areas, was among the dominants in the middle mesohaline area, possibly due to reduced salinity resulting from Tropical Storm Agnes in June, 1972 (Diaz, 1977; Jordan et al., 1976; Larsen, 1973).

Oligochaetes and Polychaetes

One of the more striking features of the James River faunal system is the distribution of two major annelid groups, the oligochaete and polychaete worms (Figure K.12). The oligochaete worms, basically fresh-water forms, are heavily concentrated throughout the entire freshwater zone and penetrate into upper reaches of the mesohaline zone. The polychaetes are marine forms and generally found in the area below Hog Island. The oligohaline zone is where both groups occur together. Among the 20 recorded dominant benthic organisms in the James River, 16 species are annelid worms (Diaz, 1977; VIMS, 1973).

Limnodrilus is the first fresh-water taxon to become a dominant in the estuarine James River where the salinity is still measurable (Figure K.13). The *Limnodrilus* spp., often cited as indicator organisms for polluted conditions, are very abundant in the Hopewell area with more than 3,000 per m^2.

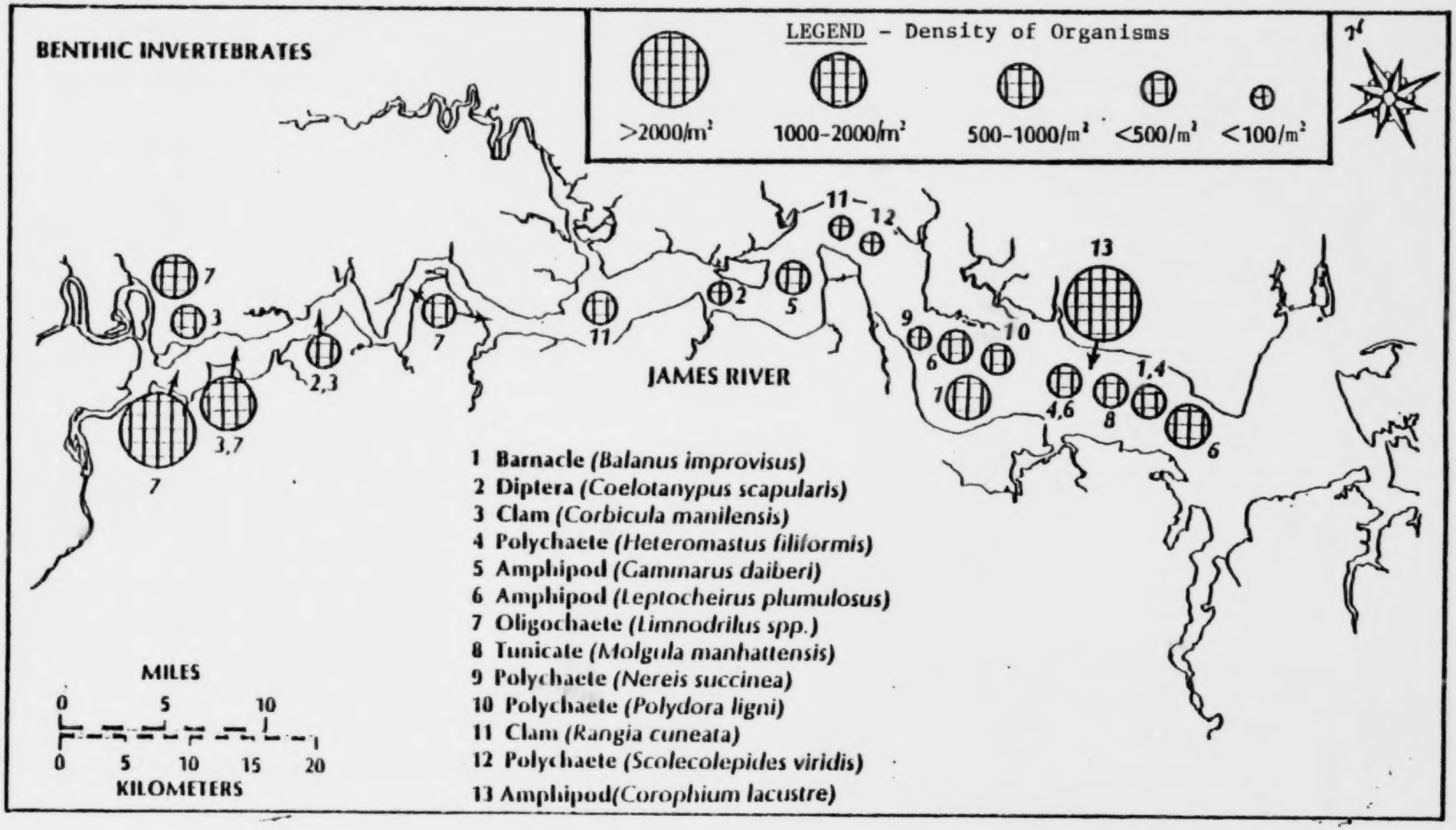

BENTHIC INVERTEBRATES
LEGEND - Density of Organisms
>2000/m²
1000-2000/m²
500-1000/m²
<500/m²
<100/m²
JAMES RIVER
1 Barnacle (Balanus improvisus)
2 Diptera (Coelotanypus scapularis)
3 Clam (Corbicula manilensis)
4 Polychaete (Heteromastus filiformis)
5 Amphipod (Gammarus daiberi)
6 Amphipod (Leptocheirus plumulosus)
7 Oligochaete (Limnodrilus spp.)
8 Tunicate (Molgula manhattensis)
9 Polychaete (Nereis succinea)
10 Polychaete (Polydora ligni)
11 Clam (Rangia cuneata)
12 Polychaete (Scolecolepides viridis)
13 Amphipod (Corophium lacustre)
MILES
0
5
10
0
5
10
15
20
KILOMETERS
7
3
3,7
2,3
11
2
5
11
12
9
6
10
13
4,6
8
1,4

FIGURE K.10. Distribution of Dominant Benthic Invertebrates During the Summer of 1972 (Cain and Peddicord, 1971; Larsen, 1974; Diaz, 1977)

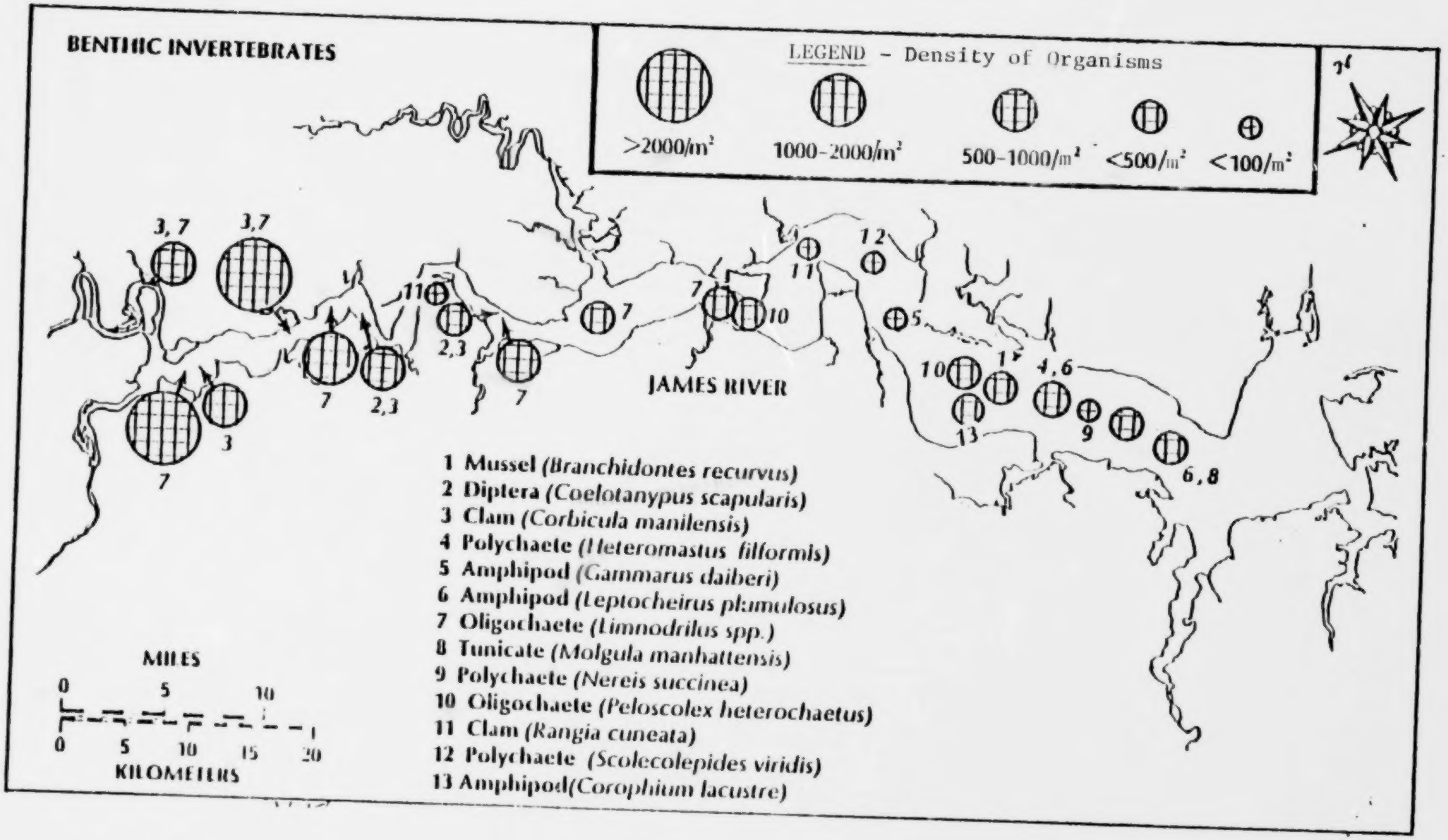

BENTHIC INVERTEBRATES
LEGEND - Density of Organisms
>2000/m²
1000-2000/m²
500-1000/m²
<500/m²
<100/m²
3, 7
3,7
7
3
7
2,3
11
2,3
7
7
7
10
JAMES RIVER
11
12
5
10
1
4, 6
13
9
6, 8
1 Mussel (Branchidontes recurvus)
2 Diptera (Coelotanypus scapularis)
3 Clam (Corbicula manilensis)
4 Polychaete (Heteromastus filformis)
5 Amphipod (Gammarus daiberi)
6 Amphipod (Leptocheirus plumulosus)
7 Oligochaete (Limnodrilus spp.)
8 Tunicate (Molgula manhattensis)
9 Polychaete (Nereis succinea)
10 Oligochaete (Peloscolex heterochaetus)
11 Clam (Rangia cuneata)
12 Polychaete (Scolecolepides viridis)
13 Amphipod(Corophium lacustre)
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE K.11. Distribution of Dominant Benthic Invertebrates During the Fall of 1972 (Cain and Peddicord, 1971; Larsen, 1974; Diaz, 1977)

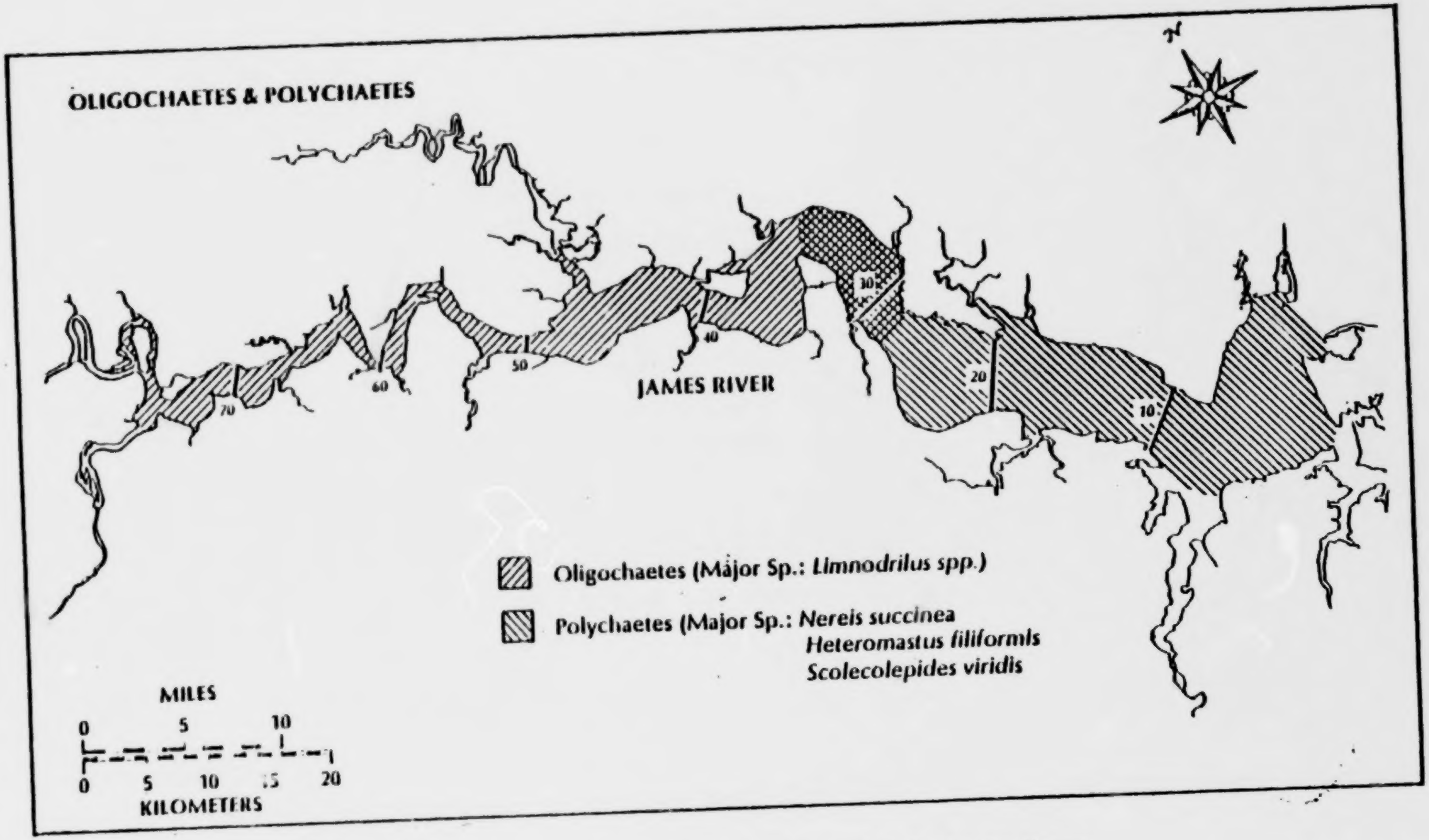

OLIGOCHAETES & POLYCHAETES
N
JAMES RIVER
10
20
30
40
50
60
70
▨ Oligochaetes (Major Sp.: Limnodrilus spp.)
▨ Polychaetes (Major Sp.: Nereis succinea
Heteromastus filiformis
Scolecolepides viridis
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE K.12. Distribution of Oligochaete and Polychaete Worms (Diaz, 1977; Engineering-Science Co., 1974)

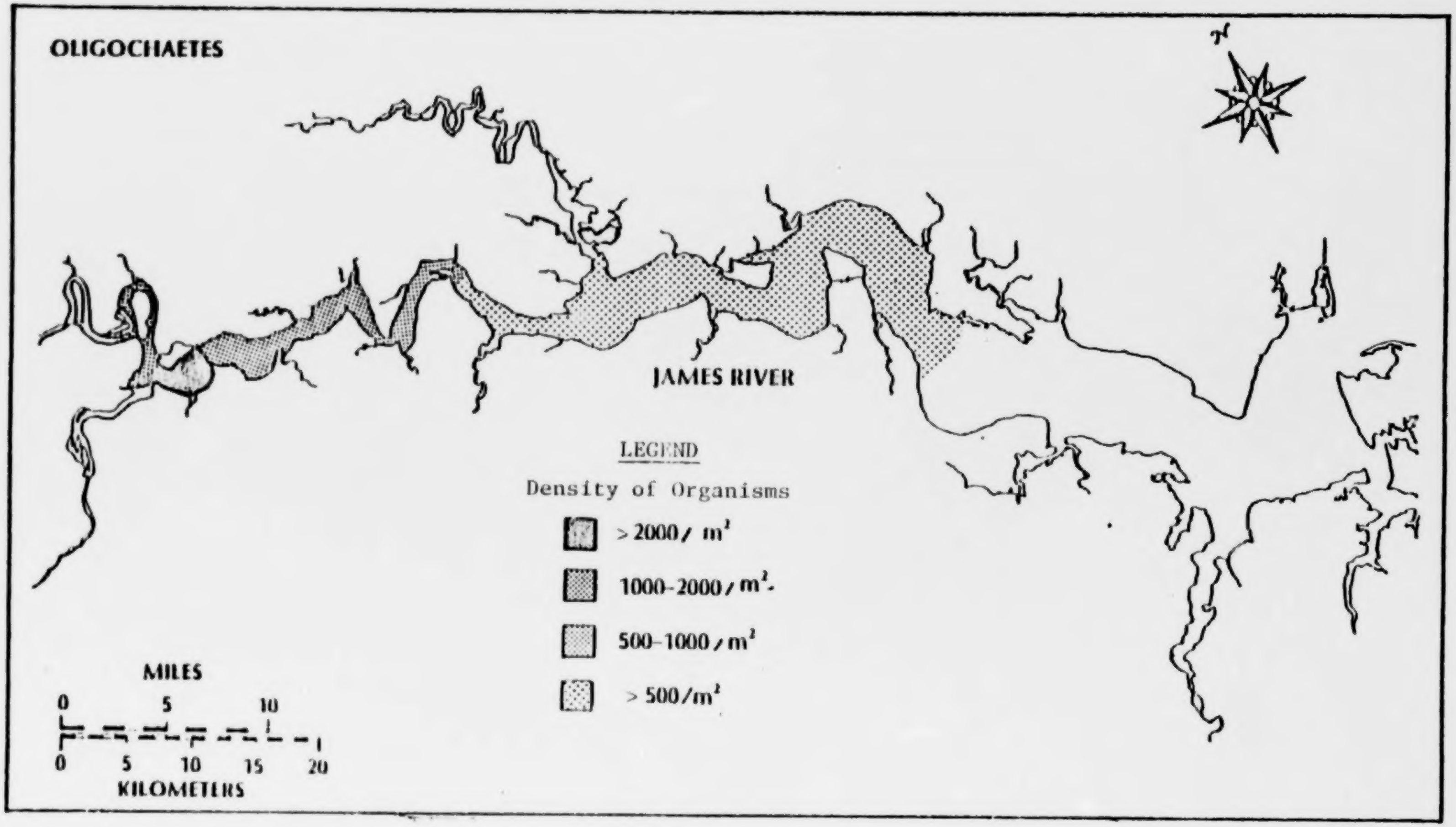

OLIGOCHAETES
N
JAMES RIVER
LEGEND
Density of Organisms
> 2000 / m²
1000-2000 / m².
500-1000 / m²
> 500/m²
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE K.13. Distribution of Oligochaete Worms, Limnodrilus spp. (Diaz, 1977)

Above and below the Hopewell area the numbers are reduced, but they are maintained above 1,000 organisms per m^2 about 28 km (15 mi) downstream from the Hopewell. The abundance of the worms is less than 500 per m^2 below RM 55 (Diaz, 1977).

The numbers of polychaete worms are not as high as the oligochaete worms and seldom reach more than 500 organisms per m^2. Nevertheless, Scolecolepides viridis was once observed reaching its maximum density of 900 per m^2 near the Surry area in the spring (Cain et al., 1972). Scolecolepides viridis is more common in the oligohaline zone, while Heteromastus filiformis and Nereis succinea are widely distributed throughout the lower estuary.

Crustacea

Blue Crab (Callinectes sapidus)

The blue crabs are distributed from the Chesapeake Bay to nearly the fresh-water zone of the James River. The blue crabs are the second most important commercial species in the Chesapeake Bay since the Bay provides almost 50% of the total catch in the U.S. (VIMS, 1973).

Blue crabs spawn in the Chesapeake Bay during the summer and early fall months. As early as August, the hatched crabs reach "first crab" stage from the planktonic larval megalopa stage and begin migrating into the river. Major nursery grounds in the James are located between RM 10 and RM 34 (VIMS, 1973).

Young crabs reach sexual maturity and legal fishing size (5 in.) in one to one and one-half years (Lippson, 1973). Adults are mainly distributed up to approximately RM 41, with a peak catch occurring at RM 31 (Figure K.14). Males remain in the brackish water throughout the year, while females are restricted to polyhaline zones. The blue crabs are very susceptible to changes in environmental conditions, e.g., DO, salinities, and pesticide concentrations (VIMS, 1973).

Molluscs

Hard Clam (Mercenaria mercenaria)
Soft Clam (Mya arenaria)
Wedge Clam (Rangia cuneata)
Asian Clam (Carbicula manilensis)

The clams are dominant molluscans in the James River. The hard and soft clams are resident species of the river. The wedge (also called "marsh" or "brackish water" clam) and Asian clams have been introduced to the James River recently.

The distribution of the hard clams is limited to waters of high salinities (15 ppth) and thus they occur only in the polyhaline zone (Figure K.15). The

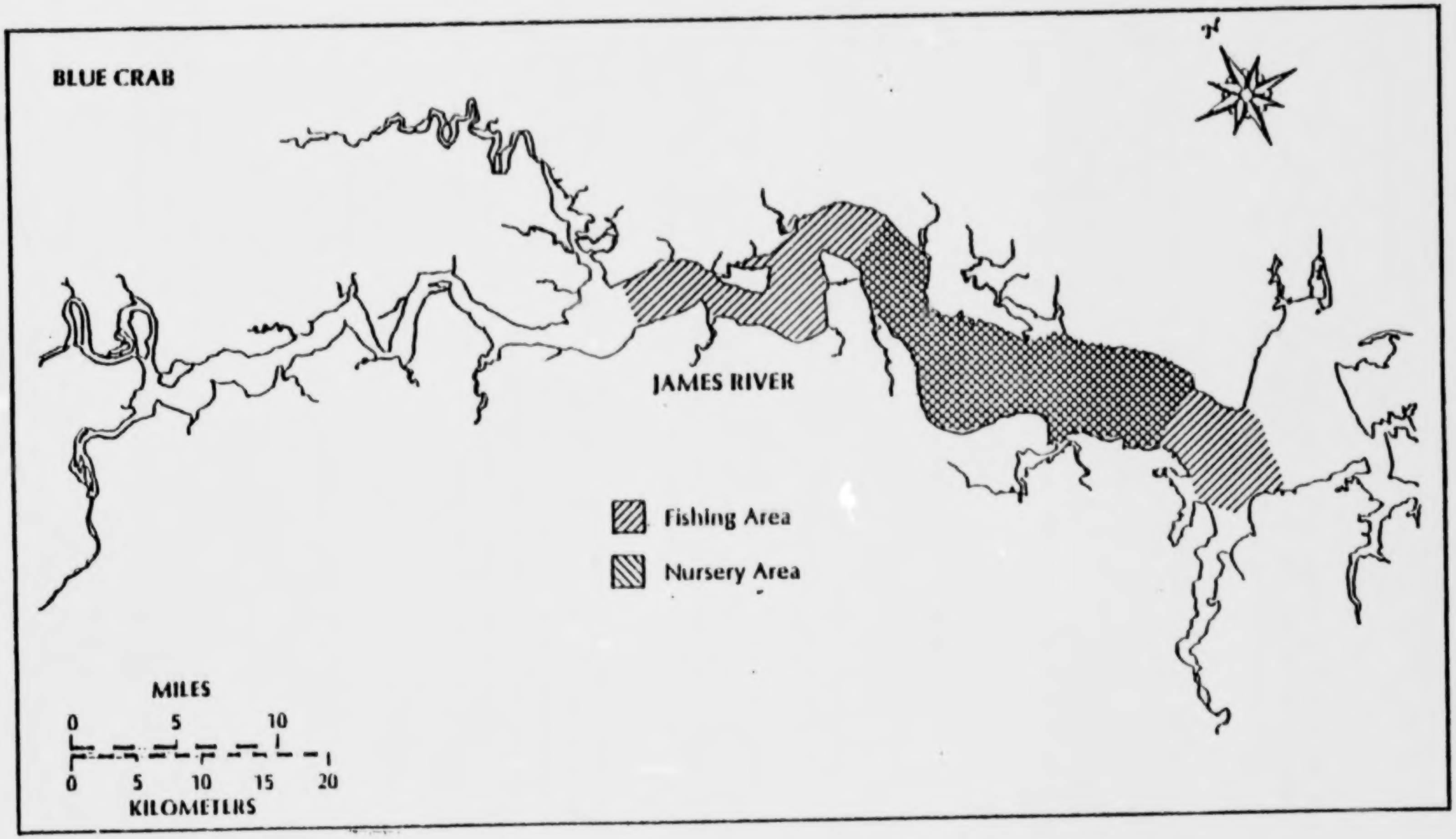

BLUE CRAB
N
JAMES RIVER
▨ Fishing Area
▧ Nursery Area
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE K.14. Fishing and Nursery Areas of Blue Crab, Calinectes Sapidus (Engineering-Science Co., 1974; VIMS, 1973)

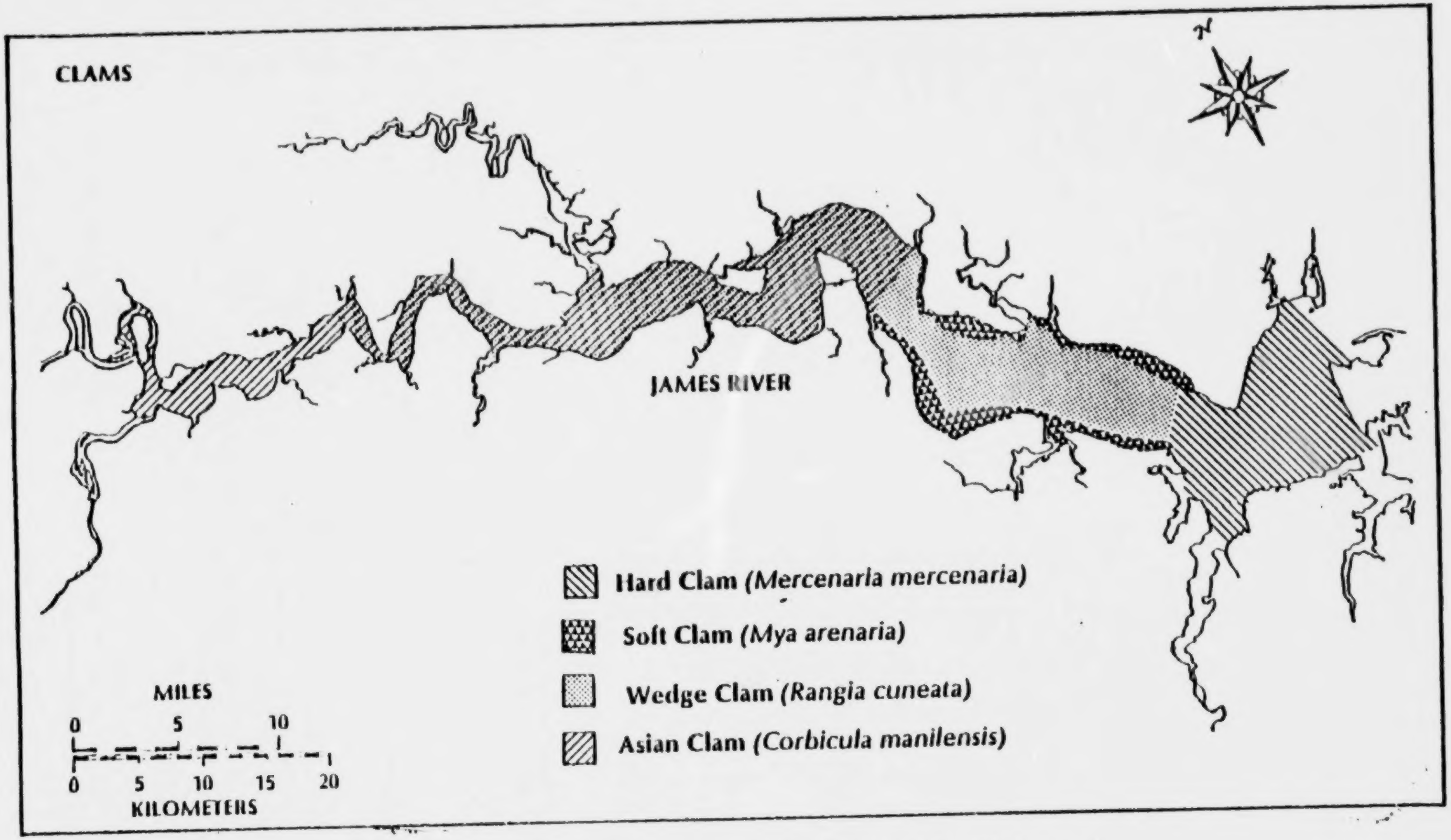

CLAMS
N
JAMES RIVER
▧ Hard Clam (Mercenaria mercenaria)
▩ Soft Clam (Mya arenaria)
▒ Wedge Clam (Rangia cuneata)
▨ Asian Clam (Corbicula manilensis)
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE K.15. Distribution of the Hard, Soft, Wedge and Asian Clams (Engineering-Science Co., 1974; Diaz, 1977)

hard clam spawns twice a year--June, July and again in September. Although young clams (under 10 mm in length) are susceptible to predators such as oyster drills and blue crabs, the mortality of larger clams is very low (VIMS, 1973; Lippson, 1973). They reach marketable size of 3.8 cm (1.5 in.) in 3 to 4 years (U.S. Army Corps of Engineers, 1974).

The soft (or steamer) clams are found in sand and sandy-mud bottoms along the shallow shores of the mesohaline James River. They spawn during the colder months of October-November and March-April. The soft clam attains a length of 7.6 cm (3 in.) in 2.5 years (U.S. Army Corps of Engineers, 1974). Since their distribution coincides with the more valuable seed oyster beds, these fast-growing and abundant clams are not yet commercially harvested in the James estuary (VIMS, 1973).

The wedge clam, a southern species, was introduced into the James River in the early 1960's. These clams are now widely distributed from approximately RM 10 to RM 65, where salinities range from 0 to more than 10 ppth (Figure K.16). Maximum concentrations of the wedge clam occur between Jamestown Island and Upper Chippokes Creek (RM 40-53) with an average density of 100 to 200 organisms per m^2 (Diaz, 1977) and a maximum density of more than 600 per m^2 (Diaz, 1977). Maximum density of more than 600 per m^2 was also reported near Surry area (Cain et al., 1972).

The Asian clam, a fresh-water species, was introduced to the James River about 1968. This species became a dominant throughout most of the tidal fresh-water zone by 1972 (Diaz, 1974). The clam has further penetrated into the oligohaline zone down to Hog Island with a salinity of as high as 5.5 ppth (Figure K.15). The biology and salt tolerance for the Asian clam are not well known (Diaz, 1977).

Biomass projections developed by VIMS yield estimates of 4×10^6 kg (9×10^6 lb) and 9×10^6 kg (20×10^6 lb) of meats for Rangia and Corbicula respectively in the James River. The Rangia estimate covers the area nautical mile 15 to 60, while that for Corbicula covers the area nautical mile 35 to 80.

American Oyster (Crassostrea virginica)

The James River estuary is the most productive and the only major source of seed oysters in Virginia. In 1971, approximately 16,000 m^3 (440,000 bushels) of seed oysters were harvested from the James River oyster beds and accounted for 76% of seed production in Virginia (Larsen, 1974). The public oystering grounds (oyster beds) occupy about 1.1×10^8 m^2 (28,000 acres) (VIMS, 1973). Major oyster beds extend from Deep Water Shoals above Mulberry Point to the mouth of the Nansemond River (Figure K.17). The most productive area is located on Wreck Shoals off the Warwick River. The oysters are subtidal and thus most of the oyster beds occur in shallow water of 3 m (10 ft) or less. Establishment of oyster beds in deeper waters is prevented by seasonal dissolved oxygen deficiencies.

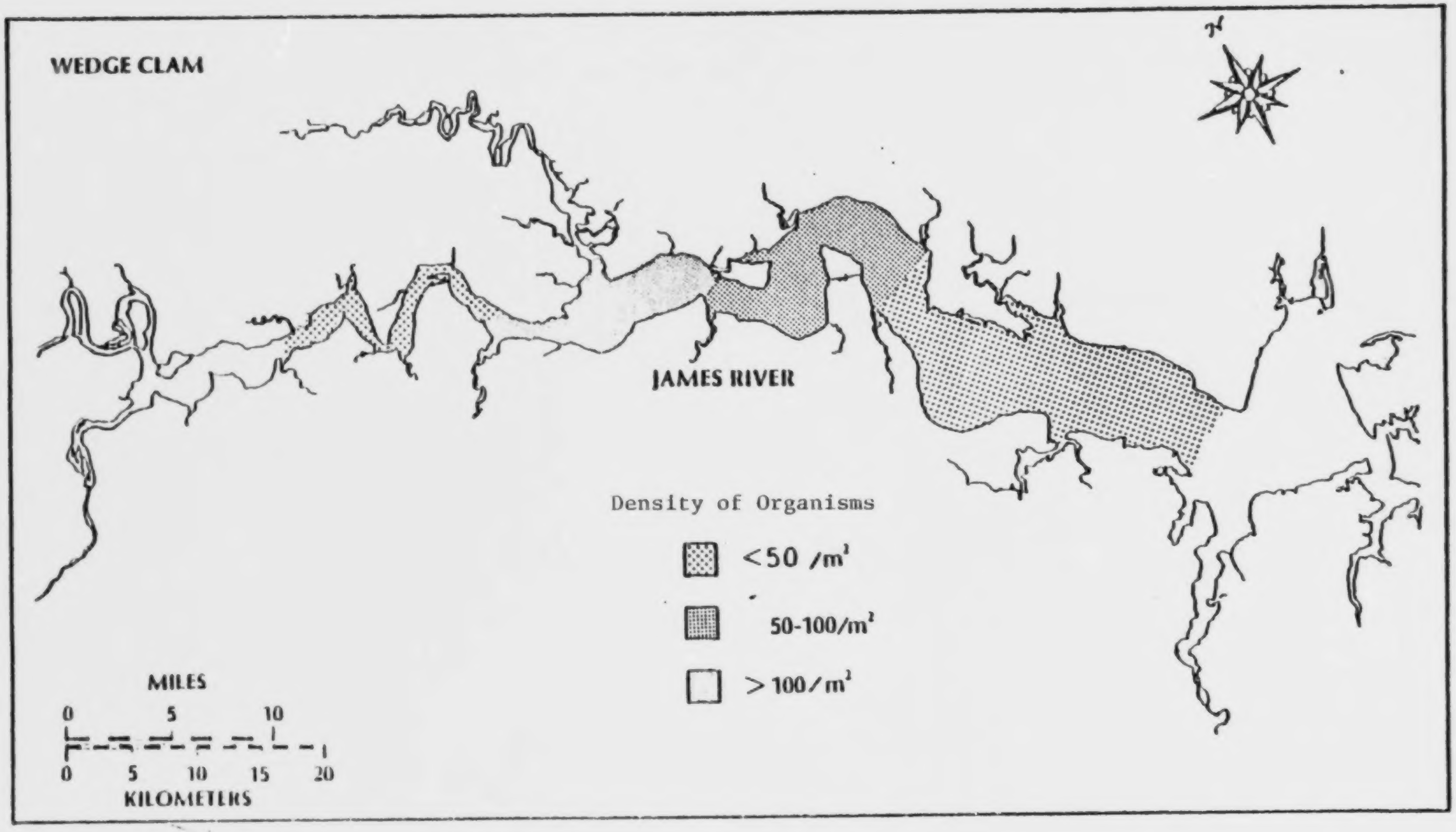

WEDGE CLAM
N
JAMES RIVER
Density of Organisms
▨ <50 /m²
▩ 50-100/m²
☐ >100/m²
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE K.16. Distribution of the Wedge Clam (Rangia Cuneata) During the Summer of 1972 (Diaz, 1977)

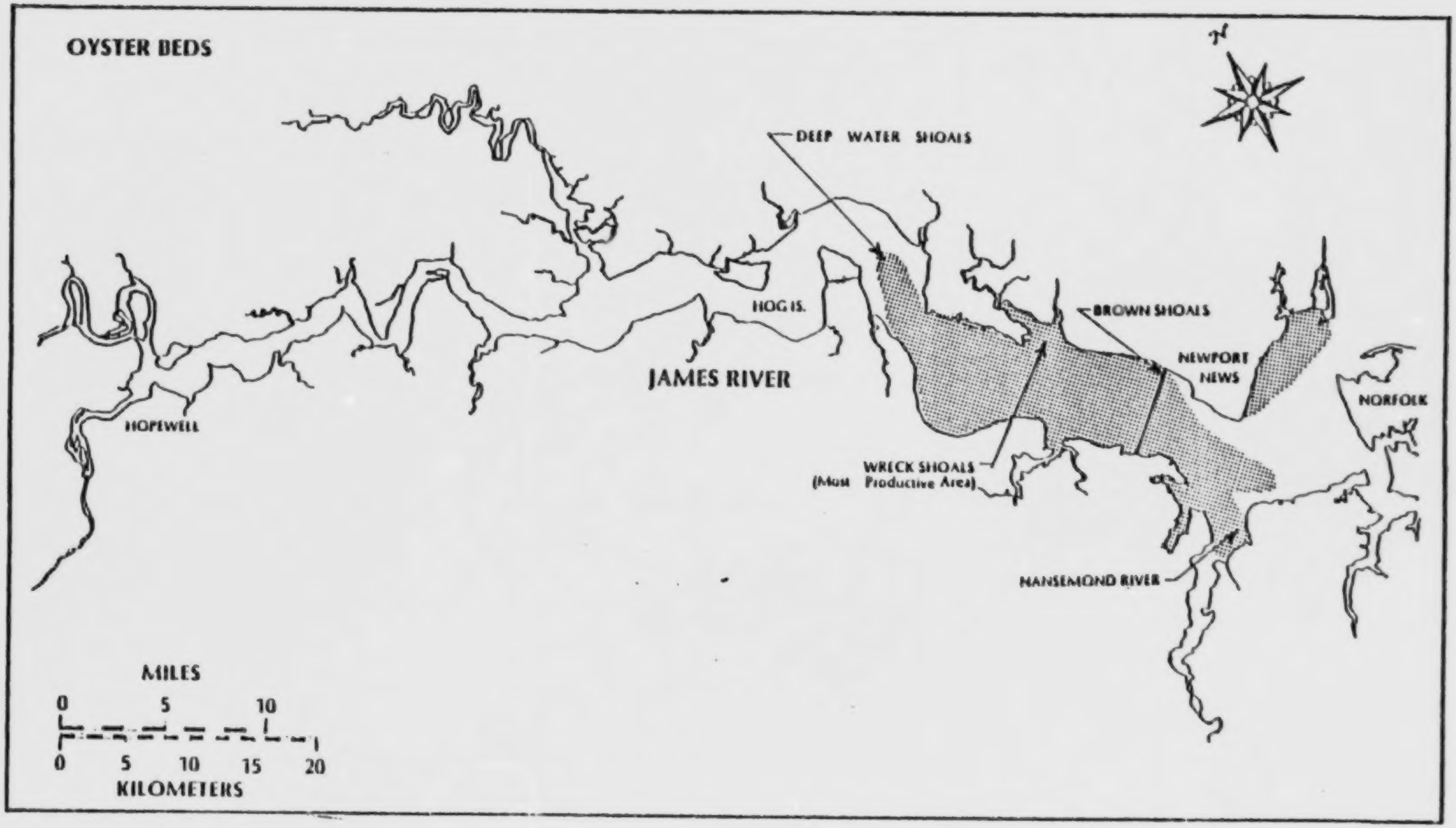

OYSTER BEDS
DEEP WATER SHOALS
BROWN SHOALS
NEWPORT NEWS
NORFOLK
HOG IS.
JAMES RIVER
HOPEWELL
WRECK SHOALS (Most Productive Area)
NANSEMOND RIVER
N
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE K.17. Distribution of Oyster Beds (Engineering-Science Co., 1974)

The oyster setting process continues from July through September with a peak setting occurring in late August and early September (VIMS, 1973; Andrews, 1951). Favorable salinities for oyster seed areas range from 6 to 15 ppth. The area below the James River Bridge where the salinity exceeds 15 ppth no longer produces commercial seed oysters due to the presence of predators and disease organisms. The prime enemies of the oysters are the oyster drills (Figure K.18), (Uroslpinx cinerea and Eupleura caudata, a fungus (Labyrinthomyxa marinum or Dermocystidium marinum) and a parasitic protozoan (Minchinia nelsoni - MSX). These organisms are mainly restricted to areas of salinities greater than 15 ppth. The oyster drills occurring in the lower salinity zone are generally smaller and cause little damage to the oysters. Many of the oyster drills in the lower estuary were killed by fresh water during the Tropical Storm Agnes in 1972, but MSX is still present (VIMS, 1973; U.S. Army Corps of Engineers, 1974; Loesch et al., 1975).

The number of oysters has been reduced recently due to overfishing, siltation, and the invasion of infestating organisms. The oyster fishery in the polyhaline zone is also hampered by the high counts of fecal bacteria.

Waterfowl

The James River marshes (Figure K.19) are one of the finest waterfowl areas in tidewater Virginia, especially the marshes of the Presquile National Wildlife Refuge near Hopewell, and Hog Island Waterfowl Management Area. The dabbling ducks such as the mallard, black duck pintail, northern shoveler, blue-winged teal, and green-winged teal are usually found in or near marshes where they feed on seeds of emergent vegetation. The marshes also attract large numbers of Canada geese and a few snow geese. A fair number of whistling swans and American coots (not a true member of the waterfowl family) are typical migrants found in these marshes (Meanley, 1975).

Protected bays, river mouths and the open river have a somewhat different waterfowl species composition from the marshes. Protected bays and river mouths, such as the Nansemond River, are likely to have diving ducks, including canvasbacks, ruddy ducks, ring-necked ducks, and redbreasted mergansers. The open river, especially at the mouth of the James, near Hampton Roads, is where the sea ducks such as the old squaw, and scoters are found, as well as other divers, such as the common goldeneye, scaup and bufflehead (Meanley, 1975).

Peak waterfowl numbers are present in December when most migrants, except the early-migrating blue-winged teal, have arrived (Fairfax Suttle, Waterfowl Biologist). Since most of the waterfowl remain for the winter, the January aerial surveys conducted by the U.S. Fish and Wildlife Service are fairly representative of migratory and wintering waterfowl use of the James River marshes (U.S. Department of the Interior, 1977).

Very few species or numbers of waterfowl remain in the marshes to breed. The primary nesting species are wood ducks, mallards, black ducks and a few blue-winged teal, plus a resident flock of 500 Canada geese located at Hog

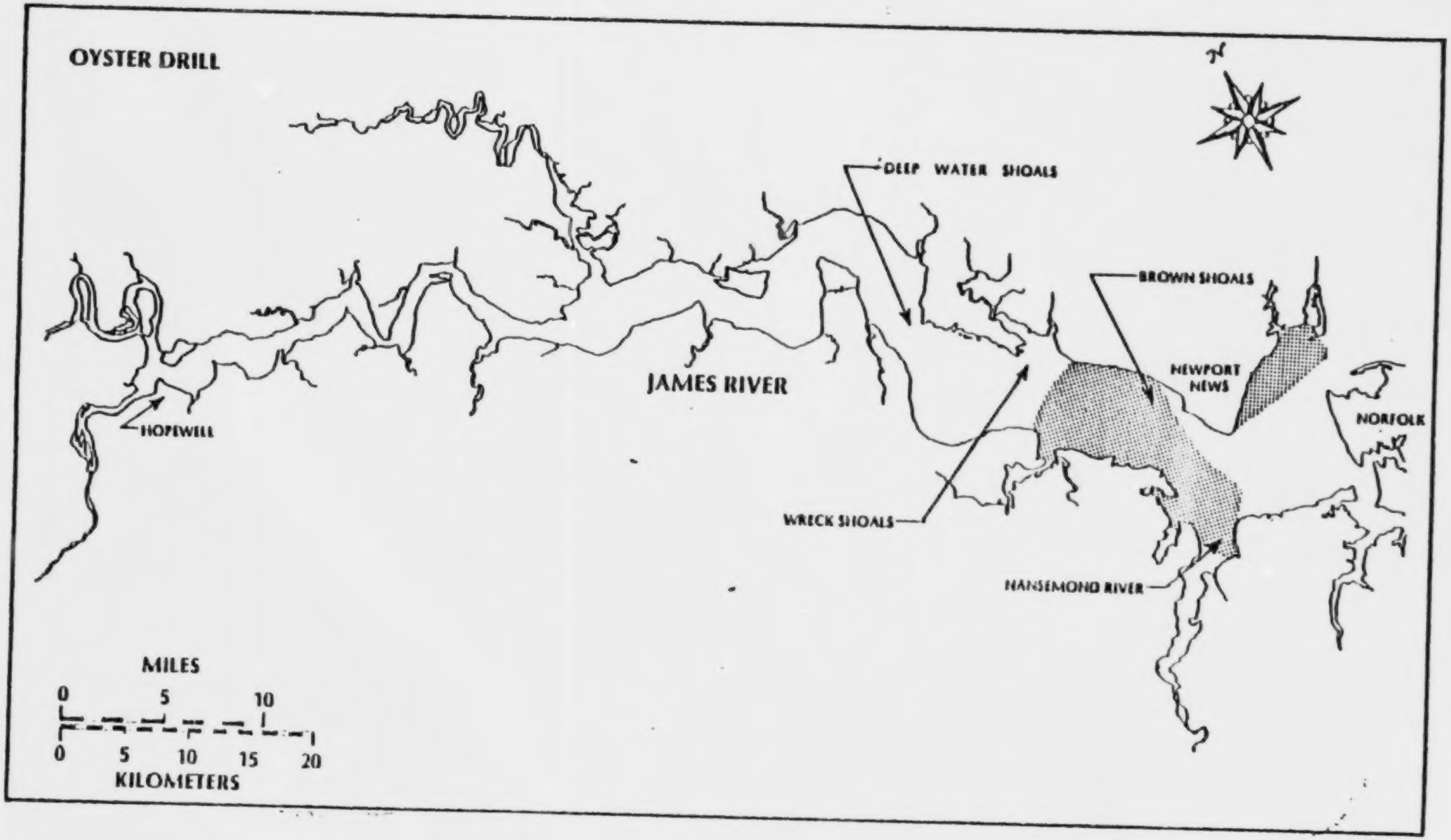

OYSTER DRILL
DEEP WATER SHOALS
BROWN SHOALS
NEWPORT NEWS
NORFOLK
JAMES RIVER
HOPEWELL
WRECK SHOALS
NANSEMOND RIVER
MILES
0
5
10
0
5
10
15
20
KILOMETERS
N

FIGURE K.18. Distribution of Oyster Drills (Engineering-Science Co., 1974)

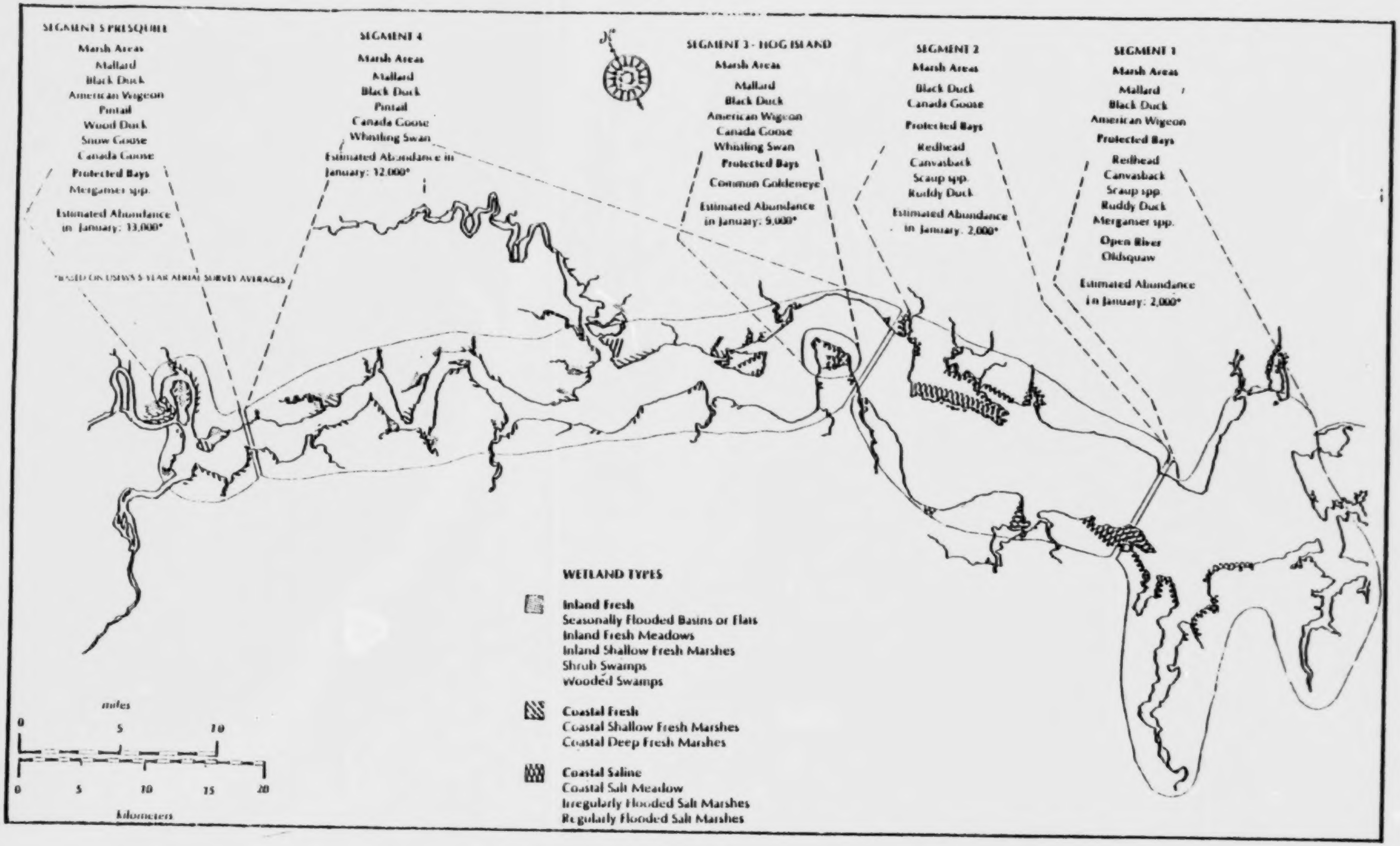

SEGMENT 5 PRESQUILE
Marsh Areas
Mallard
Black Duck
American Wigeon
Pintail
Wood Duck
Snow Goose
Canada Goose
Protected Bays
Merganser spp.
Estimated Abundance in January: 13,000*
*BASED ON USFWS 5-YEAR AERIAL SURVEY AVERAGES
SEGMENT 4
Marsh Areas
Mallard
Black Duck
Pintail
Canada Goose
Whistling Swan
Estimated Abundance in January: 12,000*
SEGMENT 3 - HOG ISLAND
Marsh Areas
Mallard
Black Duck
American Wigeon
Canada Goose
Whistling Swan
Protected Bays
Common Goldeneye
Estimated Abundance in January: 5,000*
SEGMENT 2
Marsh Areas
Black Duck
Canada Goose
Protected Bays
Redhead
Canvasback
Scaup spp.
Ruddy Duck
Estimated Abundance in January: 2,000*
SEGMENT 1
Marsh Areas
Mallard
Black Duck
American Wigeon
Protected Bays
Redhead
Canvasback
Scaup spp.
Ruddy Duck
Merganser spp.
Open River
Oldsquaw
Estimated Abundance in January: 2,000*
N
WETLAND TYPES
Inland Fresh
Seasonally Flooded Basins or Flats
Inland Fresh Meadows
Inland Shallow Fresh Marshes
Shrub Swamps
Wooded Swamps
Coastal Fresh
Coastal Shallow Fresh Marshes
Coastal Deep Fresh Marshes
Coastal Saline
Coastal Salt Meadow
Irregularly Flooded Salt Marshes
Regularly Flooded Salt Marshes
miles
0
5
10
0
5
10
15
20
kilometers

FIGURE K.19. Common Overwintering Waterfowl Species (U.S. Army Corps of Engineers, 1973; U.S. Department of the Interior 1977)

Island. Nearly all waterfowl nesting occurs at Hog Island or Presquile refuges (Personal communication from Fred Scott, editor, The Raven; Mr. Olson, manager, Presquile National Wildlife Refuge, Hopewell, 23 May 1977; and Clyde Abernathy, manager Hog Island Waterfowl Management Area, Surry, 1 June 1977).

Data on waterfowl abundance are limited primarily to the aerial survey data from the U.S. Fish and Wildlife Service taken in January, Christmas Bird Counts from Hopewell and Newport News published in American Birds, and species lists for Presquile (U.S. Department of the Interior, 1971) and Hog Island (Vepco, 1973c). Christmas bird count data for Newport News (Bystruk, 1973a-b, 1974a-b, 1975a-b, and 1976a-b) indicate that the lesser scaup and red-breasted merganser were fairly common overwintering species. These ducks are not reported by species in the U.S. Fish and Wildlife Service aerial survey data.

Shorebirds, Gulls, and Terns

Only three species of shorebirds (killdeer, greater and lesser yellowlegs) are common on the shores, beaches, or tidal flats of the James River during the breeding season (Figure K.20). Two species, the killdeer and common snipe, are common during the winter. All of the other shorebirds are present primarily during the spring and fall migration, with only a few additional species occasionally seen during the wintering or breeding seasons (U.S. Department of the Interior, 1971; Vepco, 1973c).

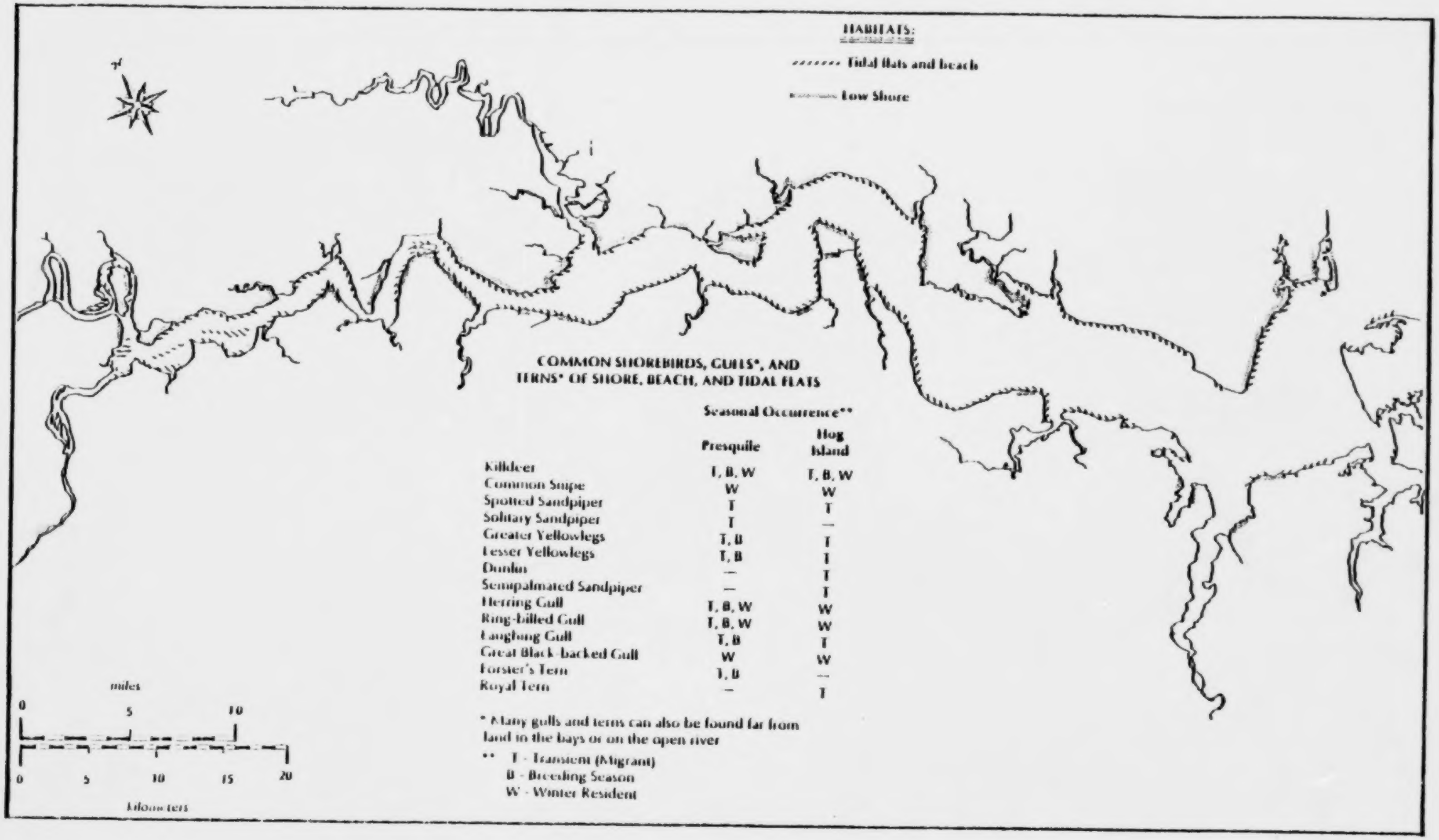
Two species of shorebirds, the common snipe and American woodcock, are game species. The snipe is a common winter resident of fresh-water meadows and marshes. The woodcock, however, is a relatively uncommon inhabitant of wet thickets and wooded swamps during the entire year (U.S. Department of the Interior, 1971; Vepco, 1973c; Sprunt and Zim, 1961).

Four species of gulls regularly seen along the James River are: the herring, ring-billed, great black-backed, and laughing gulls. Of these four, the herring and the ring-billed gulls are the most common (Meanley, 1975). In addition, the Bonaparte's Gull has been seen fairly commonly during Christmas Bird Counts at Newport News (Bystruk, 1973a-b, 1974a-b, 1975a-b, and 1976a-b). Gulls are omnivorous feeders and, although they usually eat seafood, they also visit crop fields for peanut residue, worms, grubs, and grasshoppers (Meanley, 1975).

Of the five species of terns occurring at Presquile National Wildlife Refuge and Hog Island Waterfowl Management Area, only the Forster's and royal terns are common during one or more seasons of the year. None of the terns remain during the winter (U.S. Department of the Interior, 1971; Vepco, 1973c).

Marsh and Perching Birds of the Wetlands (Excluding Waterfowl)

At least 42 species (Figure K.21) of marsh and perching birds (excluding waterfowl) are commonly found during one or more seasons in wetlands along



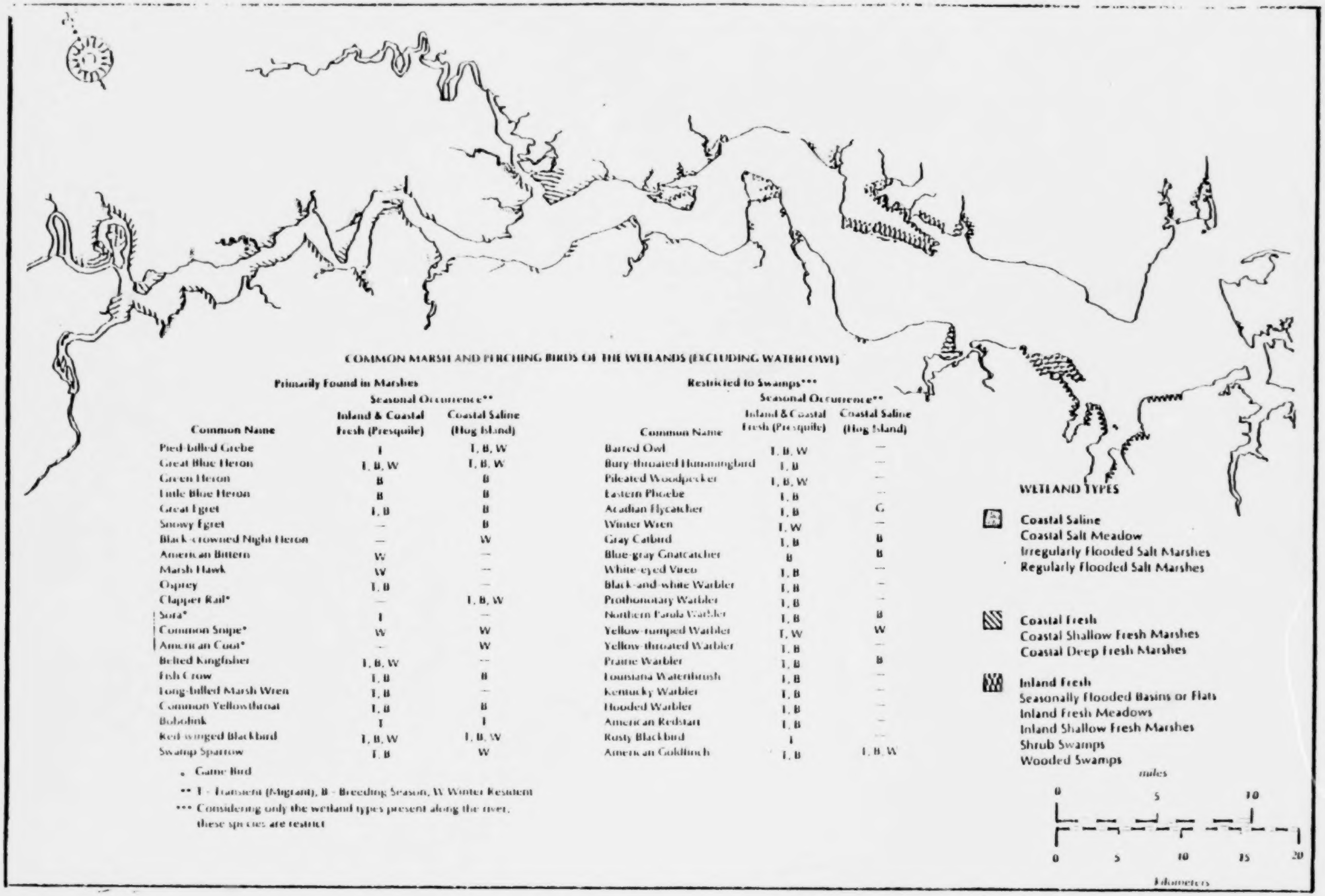
COMMON SHOREBIRDS, GULLS*, AND TERNS* OF SHORE, BEACH, AND TIDAL FLATS

	Seasonal Occurrence**	
	Presquile	Hog Island
Killdeer	T, B, W	T, B, W
Common Snipe	W	W
Spotted Sandpiper	T	T
Solitary Sandpiper	T	—
Greater Yellowlegs	T, B	T
Lesser Yellowlegs	T, B	T
Dunlin	—	T
Semipalmated Sandpiper	—	T
Herring Gull	T, B, W	W
Ring-billed Gull	T, B, W	W
Laughing Gull	T, B	T
Great Black-backed Gull	W	W
Forster's Tern	T, B	—
Royal Tern	—	T

* Many gulls and terns can also be found far from land in the bays or on the open river

** T - Transient (Migrant)
B - Breeding Season
W - Winter Resident

FIGURE K.20. Common Shorebirds, Gulls,* and Terns* of Shore, Beach and Tidal Flats (U.S. Department of the Army, 1973; U.S. Department of the Interior, 1971; Vepco 1973)



COMMON MARSH AND PERCHING BIRDS OF THE WETLANDS (EXCLUDING WATERFOWL)

Primarily Found in Marshes

Common Name	Seasonal Occurrence** Inland & Coastal Fresh (Presquile)	Seasonal Occurrence** Coastal Saline (Hog Island)
Pied-billed Grebe	T	T, B, W
Great Blue Heron	T, B, W	T, B, W
Green Heron	B	B
Little Blue Heron	B	B
Great Egret	T, B	B
Snowy Egret	—	B
Black-crowned Night Heron	—	W
American Bittern	W	—
Marsh Hawk	W	—
Osprey	T, B	—
Clapper Rail*	—	T, B, W
Sora*	T	—
Common Snipe*	W	W
American Coot*	—	W
Belted Kingfisher	T, B, W	—
Fish Crow	T, B	B
Long-billed Marsh Wren	T, B	—
Common Yellowthroat	T, B	B
Bobolink	T	T
Red-winged Blackbird	T, B, W	T, B, W
Swamp Sparrow	T, B	W

* Game Bird

** T - Transient (Migrant), B - Breeding Season, W Winter Resident

*** Considering only the wetland types present along the river, these species are restrict

Restricted to Swamps***

Common Name	Seasonal Occurrence** Inland & Coastal Fresh (Presquile)	Seasonal Occurrence** Coastal Saline (Hog Island)
Barred Owl	T, B, W	—
Ruby-throated Hummingbird	T, B	—
Pileated Woodpecker	T, B, W	—
Eastern Phoebe	T, B	—
Acadian Flycatcher	T, B	G
Winter Wren	T, W	—
Gray Catbird	T, B	B
Blue-gray Gnatcatcher	B	B
White-eyed Vireo	T, B	—
Black-and-white Warbler	T, B	—
Prothonotary Warbler	T, B	—
Northern Parula Warbler	T, B	B
Yellow-rumped Warbler	T, W	W
Yellow-throated Warbler	T, B	—
Prairie Warbler	T, B	B
Louisiana Waterthrush	T, B	—
Kentucky Warbler	T, B	—
Hooded Warbler	T, B	—
American Redstart	T, B	—
Rusty Blackbird	T	—
American Goldfinch	T, B	T, B, W

WETLAND TYPES

▨	Coastal Saline Coastal Salt Meadow Irregularly Flooded Salt Marshes Regularly Flooded Salt Marshes
▧	Coastal Fresh Coastal Shallow Fresh Marshes Coastal Deep Fresh Marshes
▦	Inland Fresh Seasonally Flooded Basins or Flats Inland Fresh Meadows Inland Shallow Fresh Marshes Shrub Swamps Wooded Swamps

FIGURE K.21. Common Marsh and Perching Birds of the Wetlands (Excluding Waterfowl)(U.S. Department of the Interior, 1971; U.S. Army Corps of Engineers, 1973, Vepco, 1973; Wass, 1972)

the James River (U.S. Department of the Interior, 1971; Vepco, 1973c). Half of these species are normally found only in the swampy wetlands, especially the swamps with large trees. Some of the species associated with the marshes are more abundant in fresh-water marshes (e.g. sora and common snipe); others are more common in salt-water marshes (e.g. snowy egret and clapper rail). All of the above, plus numerous additional species migrate through the Lower Chesapeake Bay area and are described by Wass (1972) as to their abundance and habitat preferences.

Two species of raptors known to frequent the James River marshes are of concern due to low population levels. The southern bald eagle, which is on the Federal Endangered Species list, no longer nests along the James River, but is frequently seen between Richmond and Hog Island (personal communication, M.L. Wass, biologist, Virginia Institute of Marine Science). The osprey, which is on the Audubon Society's "Blue List' (Arbib, 1976), is present at Presquile National Wildlife Refuge during April and May (personal communication, Mr. Olson, manager, Presquile), but does not nest anywhere along the James. Both raptors are showing slight population increases in nearby areas of the Chesapeake Bay (Wass, personal communication).

The large roosts of red-winged blackbirds in the lower James River basin are particularly impressive. These grain-eating birds group together in tidal marshes at night during the fall and winter in roosts numbering up to 500,000 birds or more. One important attraction are the nearby peanut fields, but the redwings also feed on corn, sorghum, weed seeds, and insects (Meanley, 1975).

The "reedbird" or bobolink can also be found roosting in large numbers in fresh and brackish river marshes, although it does not remain for the winter like the red-winged blackbird. The bobolink nests in meadows, but migrates to the coast in late summer to feed on wild rice, millet and other aquatic plant seeds.

Four species of rails, all game birds, have been reported from the James River marshes. The sora and clapper rails are relatively common, while the king and Virginia rails are less abundant (U.S. Department of the Interior, 1971; Vepco, 1973c). Crustaceans, insects, and small fish are important foods of these secretive marsh inhabitants, but the king and sora rails also eat a large quantity of plant food during the winter (Sprint and Zim, 1961).

Mammals

Wetlands provide the food, cover, nesting areas, and other essentials necessary for several species of mammals (e.g. mink, muskrat) to complete their life cycle within the limits of wetlands. These communities also provide food or cover for species (e.g. deer, fox) that depend on other types of habitats (e.g. uplands) for resources necessary to maintain their existence.

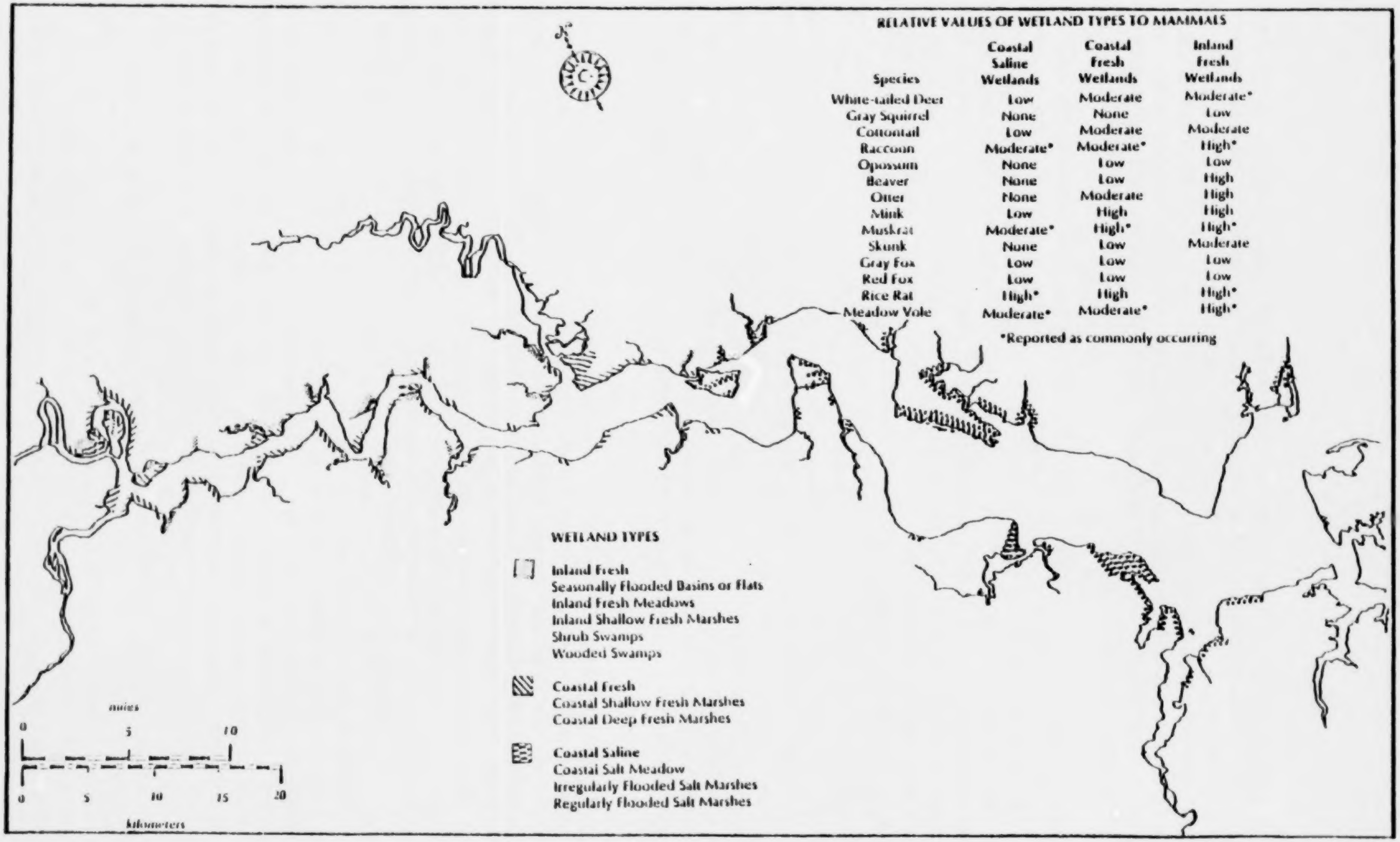
The coastal saline wetlands, which occur between the mouth of the James River and approximately Jamestown Island, support substantial populations of muskrat and raccoon. Muskrats are among the most important mammals in the brackish marshes and are especially abundant in areas of Olney three-square, a preferred food, and humus, which allows construction of tunnels and canals. Meadow voles and rice rats are often found in association with muskrats and may inhabit the muskrats' lodges in areas with fluctuating water levels (Meanley, 1975). Raccoon, muskrat, and rice rats are among the most common mammals at the Hog Island Waterfowl Management Area, located near the boundary with coastal fresh wetlands. Gray fox are common in the area of Hog Island while mink and otter are uncommon residents (Vepco, 1976). Other mammals present which may use the wetlands include white-tailed deer and cottontails (U.S. Army Corps of Engineers, 1973). The value of wetlands to mammals in the region is shown in Figure K.22.

The coastal fresh wetlands extend approximately from Jamestown Island to Richmond. These are fresh-water marshes where the water levels are affected by the tidal fluctuations. Inland fresh wetlands occupy the upper reaches of the James and along its tributaries where there is little or no tidal fluctuation. There are few inland fresh wetlands in the study area except around Presquile National Wildlife Refuge. The fresh wetland areas have lower biological productivity than the saline wetlands, but because they have a greater vegetation diversity they support a larger array of mammalian species. Inland wetlands provide more resources to mammals than do the coastal wetlands (see Figure K.22). The fresh wetlands at Presquile National Wildlife Reserve are used extensively by muskrat and raccoon (U.S. Department of the Interior, 1975); red fox, white-tailed deer, cottontail, gray squirrel, opossum, and striped skunk are also present (personal communication, Mr. Olson, Manager, Presquile).

Vascular Plants

The tidal James River is in the Atlantic Coastal Plain and is within the broadleaf-needleleaf forest, or specifically an oak-hickory-pine forest. The first flora of Virginia was based on John Clayton's collection and described by Gronovius (1762). Fernald (1939), Massey (1950), and others have described and listed plants growing along the James River. The vascular flora along the river consists mainly of marshes and swamps (Figure VI.26) and can be divided into three main categories of wetlands based on the classification of Shaw and Fredine (1971).

Coastal Saline Wetlands. "Regularly flooded salt marshes" are where the soil is covered at average high tide with six inches or more of water during the growing season. The vegetation is mainly saltmarsh cordgrass (*Spartina alterniflora*), eelgrass (*Zostera marina*), and widgeon grass (*Ruppia maritima*). In Virginia, saltmarsh cordgrass may produce up to 6 tons/acre/year or 95% of the seaside marsh vegetation (Wass, 1972). "Irregularly flooded salt marshes" are where the soil is covered by wind tides due to storms at irregular intervals during the growing season. The vegetation is dominantly black needlerush



WETLAND TYPES
[ ] Inland Fresh
Seasonally Flooded Basins or Flats
Inland Fresh Meadows
Inland Shallow Fresh Marshes
Shrub Swamps
Wooded Swamps
▨ Coastal Fresh
Coastal Shallow Fresh Marshes
Coastal Deep Fresh Marshes
▩ Coastal Saline
Coastal Salt Meadow
Irregularly Flooded Salt Marshes
Regularly Flooded Salt Marshes
miles
0
5
10
0
5
10
15
20
kilometers

RELATIVE VALUES OF WETLAND TYPES TO MAMMALS

Species	Coastal Saline Wetlands	Coastal Fresh Wetlands	Inland Fresh Wetlands
White-tailed Deer	Low	Moderate	Moderate*
Gray Squirrel	None	None	Low
Cottontail	Low	Moderate	Moderate
Raccoon	Moderate*	Moderate*	High*
Opossum	None	Low	Low
Beaver	None	Low	High
Otter	None	Moderate	High
Mink	Low	High	High
Muskrat	Moderate*	High*	High*
Skunk	None	Low	Moderate
Gray Fox	Low	Low	Low
Red Fox	Low	Low	Low
Rice Rat	High*	High	High*
Meadow Vole	Moderate*	Moderate*	High*

*Reported as commonly occurring

FIGURE K.22. Mammals Associated with the James River (U.S. Army Corps of Engineers; 1973, Meanley, 1973; U.S. Department of the Interior, 1975)

(*Juncus roemerianus*) and widgeon grass with shrub species such as marsh elder (*Iva frutescens*) and groundsel tree (*Baccharis halimfolia*). "Coastal salt meadows" are where the soil is always water-logged during the growing season, but rarely covered with tidewater. The vegetation is mainly saltmeadow hay (*Spartina patens*), saltgrass (*Distichlis spicata*) and blackneedle rush. In fresher parts, one finds Olney threesquare (*Scripus olneyi*) and saltmarsh feabane (*Pluchea foetida*).

Coastal Fresh Areas. "Coastal shallow fresh marshes" are where the soil is always water-logged during the growing season and it may be covered at high tide with as much as 6 in. of water. These marshes are on the landward side of deep marshes along tidal rivers, sounds, and deltas. The vegetation consists of big reed cordgrass (*Spartina cynosuroides*) which forms dense stands in shallow marshes, *Carex* spp., bulrushes (*Scirpus robustus* and other species), spike rushes, marsh flebane, threesquare, sawgrass (*Cladium jamaicense*), cattails, (*Typha* spp.), arrowheads (*Sagittaria* spp.), smartweeds (*Polygala* spp.) and arrow-arum (*Peltandra virginica*). "Coastal deep marshes" are where the soil is covered at average high tide with 6 in. to 3 ft of water during the growing season. These marshes occur along tidal rivers and bays. The vegetation is cattails (*Typha latifolia* and *T. angustifolia*), wild rice (*Ziziana aquatica*), pickerelweed (*Pontederia cordata*), rice cutgrass (*Leersia oryzoides*), submerged plants such as *Potomageton* spp., and bigstem panic grass (*Panicum virgatum*). Common reed (*Phragmites communis*) is put into this category of coastal deep marshes but it is not known to have yet invaded the marshes of the James River (U.S. Army Corps of Engineers, 1973; Wass, 1972).

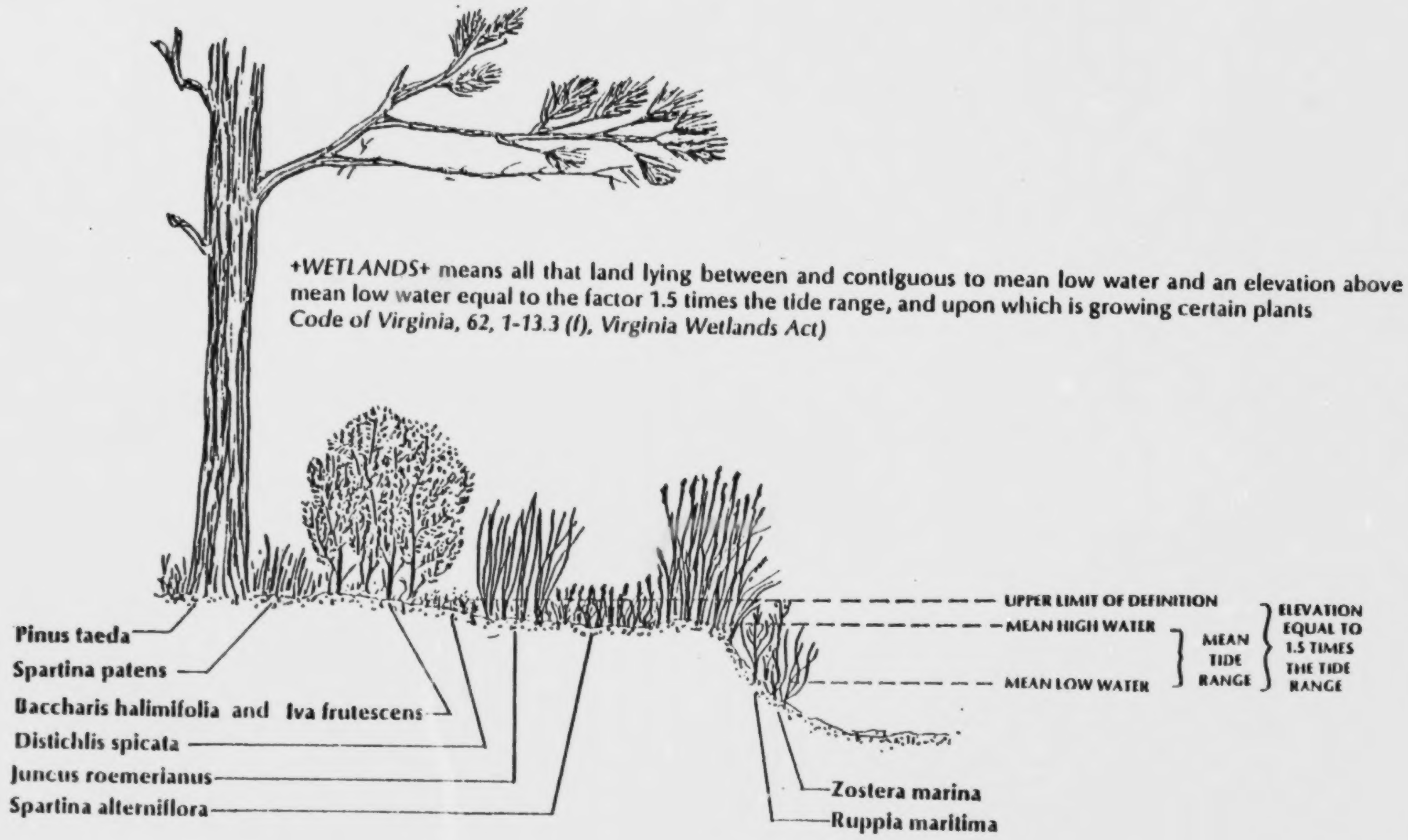
Inland Fresh Areas. "Seasonally flooded basins or flats" are where the soil is covered with water, or just water-logged during variable seasonal periods but usually drained during much of the growing season. This type is found both in upland depressions and in overflow bottom lands. Seasonal flooding occurs and vegetation varies according to the season and duration of flooding. The vegetation includes hardwood (*Quercus* spp., *Acer rubrum*, *Ilex opaca*, *Carya* sp., *Liquidambar styraciflua*, *Fraxinus pennsylvanica*, *Ulmus* sp., *Platanus occidentalis*), smartweeds, millet (*Echinoclea walteri*), teargrass, edible nutgrass (*Cyperus esculentus*), marsh elder, and cocklebur (*Xanthium strumarium*). The "inland fresh meadows" occur where the soil is usually without standing water during most of the growing season but is water-logged within at least a few inches of its surface. The vegetation consists of grasses, sedges, rushes, and various broad-leafed plants. "Inland shallow fresh marshes" are where the soil is usually water-logged during the growing season and is often covered with as much as 6 in. or more of water. The vegetation includes sawgrass, arrowheads, and pickerelweeds. "Shrub swamps" are where the soil is usually water-logged during the growing season and is often covered with 6 in. of water. The vegetation consists of alder (*Alnus serrulata*), willow (*Salix nigra*), buttonbush (*Cephalanthus occidentalis*), and dogwood (*Cornus sticta*). "Wooded swamps" are where the soil is water-logged at least within a few inches of its surface during the growing season and is often covered with as much as 0.3 m (1 ft) of water. The vegetation consists of water oak (*Quercus nigra*), tupelo gum (*Nyssa aquatica*), swamp black gum

(N. sylvatica), and bald cypress (Taxodium distichum). A list of vascular plants (nearly 350 species) known to occur along the lower James River is given in Appendix D along with habitat type. A typical cross section of wetland area is shown in Figure K.23.

Marshes are extremely productive of plant biomass due to the density of vegetation, physically rich in nutrients, abundant water, relative rapid rate of decomposition of organic matter and other factors which are reviewed by Keefe (1972). Marsh areas are between two and ten times more productive than the James River (Engineering-Science Co., 1974). Productivity figures for seven community types found along the James River (Table K.1) are based on Silberhorn et al. (1974) and Moore (1976). Marshes are extremely important habitats for commercial and sport fishes. In Virginia, 95% of these fishes are dependent on these marshes (Silberhorn, 1976).

Erosion plays a large role in the distribution of plant communities. The rate of erosion has been decreasing along the James River in the past years due to protection measures in unstable areas and the requirement of a permit before any activity is performed (Virginia Code, 1975). The areas of erosion and accretion activity are diagrammed (Figure K.24). The shoreline of Presquile National Wildlife Refuge bordering Turkey Island cutoff has been experiencing erosion recently (Owen et al., 1975a) due to wind and wave action. In Charles City County erosion is also due to downhill rain runoff (Owen et al., 1976a) and heavy upstream rains which undermine trees. Roots of the fallen trees are dislodged allowing for additional erosion. Shoreline erosion in Surry County averages 0.3 to 0.85 m per year (1.0 to 2.8 ft per year (Owen et al., 1976b) with most of the sediments coming from the Eastover area. In James City County the shoreline erosion rate per year is 0.6 m (2 ft) for the area between Skiffes and College Creeks and is especially severe at First Colony--nearly 0.3 m (1 ft) a month (Hobbs et al., 1975b). Riprap, gabions, bulkheads, and revetments are used for erosion prevention and thus one would not expect to find established vegetation in these areas. Isle of Wight County has little erosion due to extensive marshes along the creeks.

In recent times, with erosion protection measures, areas have become revegetated, such as along Mogarts Beach (Owen et al., 1975b). Ragged Island marshes and shorelines erode at a rate of 0.37 to 0.79 m per year (1.2 to 2.6 ft per year). Ninety-four percent of the City of Suffolk (formerly Cities of Suffolk and Nansemond) shoreline is marsh and the remainder is beach (3%) and artificially stabilized (2%). Shoreline erosion problems of Newport News are not significant (Hobbs et al., 1975c). The same is true for the City of Hampton portion that borders on the James River (Hobbs et al., 1975a) as the shoreline is protected by bulkheads or seawalls. Exceptions to this are small areas in the vicinity of Hampton Roads Bridge, along Malo Beach in the Chesapeake Bay.



+WETLANDS+ means all that land lying between and contiguous to mean low water and an elevation above mean low water equal to the factor 1.5 times the tide range, and upon which is growing certain plants *Code of Virginia, 62, 1-13.3 (f), Virginia Wetlands Act)*

Pinus taeda
Spartina patens
Baccharis halimifolia and Iva frutescens
Distichlis spicata
Juncus roemerianus
Spartina alterniflora
Zostera marina
Ruppia maritima
UPPER LIMIT OF DEFINITION
MEAN HIGH WATER
MEAN LOW WATER
MEAN TIDE RANGE
ELEVATION EQUAL TO 1.5 TIMES THE TIDE RANGE

FIGURE K.23. Plant Relations for Tidal Wetlands (Adapted From Silberhorn et al., 1974)

TABLE K.1. PRODUCTIVITY RATES OF MARSH COMMUNITIES AND ENVIRONMENTAL CONTRIBUTIONS (SILVERHORN ET AL., 1974; MOORE 1976)

Community Type	Yield(tons/acre/year)	Environmental Contribution
I. *Spartina alternifolia*	4	Optimum detritus, roots and rhizomes are food, deterrant to shoreline erosion, sediment trap, rated highest in priority
II. *S. patens*	1-2	Erosion deterrent, filters sediments and wastes
III. *Juncus roemerianus*	3-5	Highly resistant to erosion, traps sediments, but not as effective as II
IV. *Iva frutescens*/ *Baccharis halimifolia*	2	Effective trap for flotsam, adds diversity to the ecosystem
V. *Spartina cynosurioides*	3-6	Detritus less available than in I, effective erosion buffer, flood water assimilation
VI. *Typha* spp.	2-4	Traps upland sediments, food for wildlife
VII. *Peltandra virginica*/ *Pontederia cordata*	2-4	Detritus available to marine environment, susceptible to erosion, especially in winter months

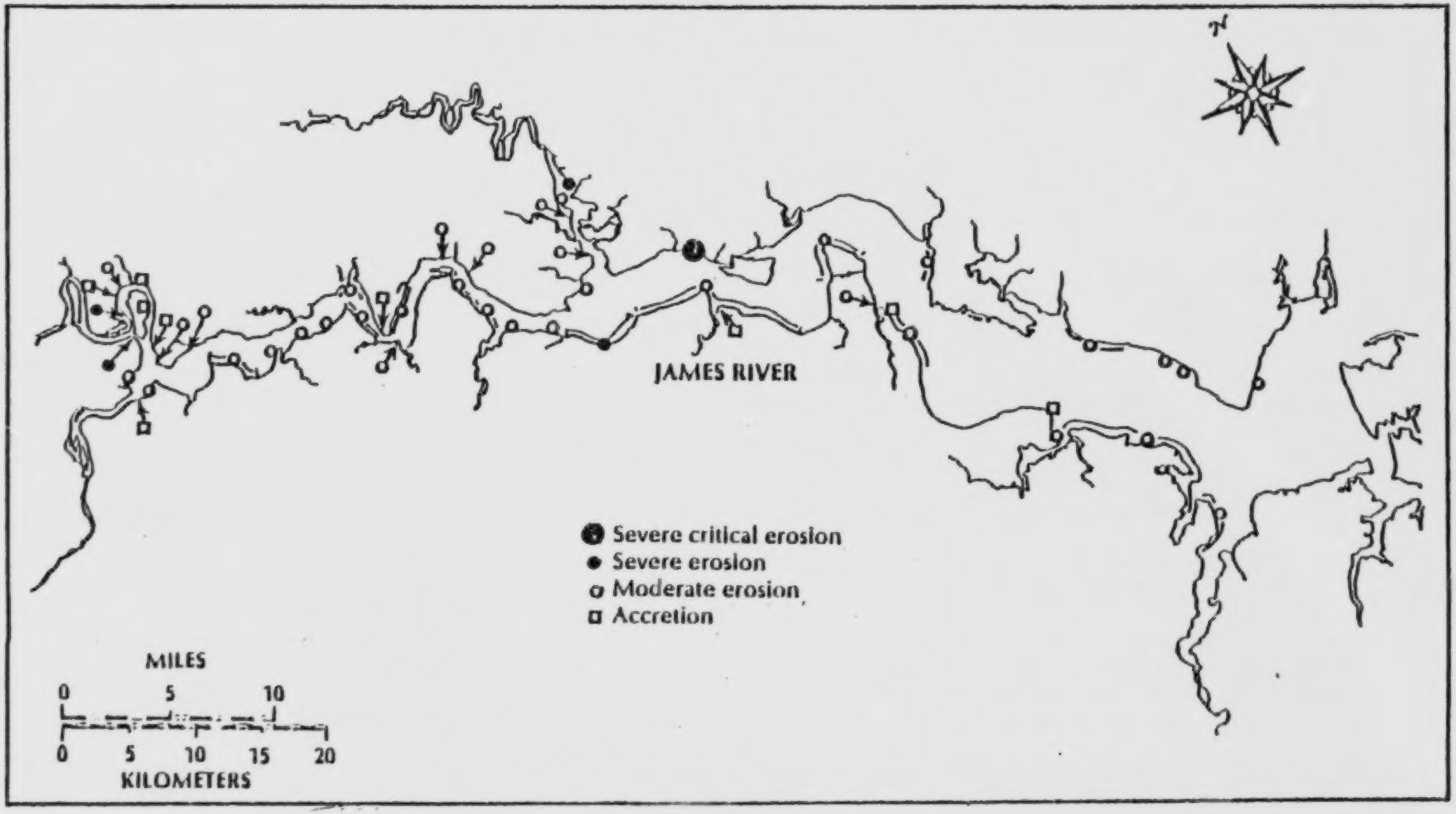

N
JAMES RIVER
Severe critical erosion
Severe erosion
Moderate erosion
Accretion
MILES
0
5
10
0
5
10
15
20
KILOMETERS

FIGURE K.24. Areas of Soil Erosion and Deposition (Hobbs III et al., 1975a,b,c; Owen et al., 1975a,b, 1976a,b,c; Rogers et al., 1976)

The acreage of tidal marshes and swamps for the James River given by VIMS (1973) is 12,298 (Table K.2) or 5 x 10^7 m^2. Their subtotal and total figures are less than those given by Wass and Wright (1969) since areas not affected by the flowing James River were excluded in this study.

A detailed county inventory of the wetlands, including mapping of the vascular plant species at the scale of 1:24,000, is being conducted by VIMS (Personal communication, Dr. Gene M. Silberhorn, project leader, 21 June 1977). Funding is partly from the U.S. Department of Commerce, NOAA, Office of Coastal Zone Management. This study is utilizing remote sensing provided by NASA Langley and NASA Wallops Flight Centers, Virginia Department of Highways and Transportation, and VIMS, which is extensively supported by ground truth. A separate volume for each county and city area is being prepared.

Two published studies on mapping the vascular flora of the river have been made. A diked disposal area was mapped by Silberhorn and Barnard (in Peloquin et al., 1975) during a natural plant succession study on an island less than two square acres near Windmill Point (RM 58). Three years after completion of dredged material deposition on the tidal flat, 58 species of vascular plants were identified which is a relatively high diversity for so small an area. A vascular flora map for Jamestown Island was prepared by Loetterle (1970) with emphasis on tree species.

TABLE K.2. Marsh and Swamp Acreage (VIMS, 1973)

Water/Land Feature Name	USGS Topo Quadrangle	Marsh Area		Swamp Area
Hoffler Creek	Newport News S	171		--
Ragged Island	Newport News S, Benn's Church	310, 411		--
Mulberry Island	Mulberry Island, Yorktown	1275		--
Lawnes Creek	Hog Island, Bacon's Castle	680		--
Hog Island	Yorktown	410		--
Chippokes Creek	Hog Island	362		--
College Run	Hog Island, Surry	--		213
Grove Creek	Hog Island	110		--
Passmore Creek	Surry	295		--
Back River	Surry	119		--
Pitch and Tar Swamp	Surry	150		--
Sandy Bay	Surry	200		--
Powhatan Creek	Surry	235		95
Grays Creek	Surry	603		390
Kennon Marsh	Charles City	410		266
Kittewan Creek	Charles City	296		148
Weyanoke Point	Charles City	170		--
Hundred Creek	Charles City	--		100
Flowerdew Hundred	Charles City	--		128
Herring Creek	Westover	314		310
Harrison Lake	Westover	--		120
Powell Creek	Westover	165		452
Chappell Creek	Westover	--		110
Jenny Creek	Westover	--		106
Eppes Creek and Island	Westover	--		147
Eppes Island	Hopewell	--		159
Bailey Creek	Hopewell	--		309
Eppes Creek	Hopewell	--		132
Johnson's Creek	Hopewell	--		200
Presque Isle	Hopewell	--		600
Curles Neck	Hopewell	160		817
Turkey Island	Dutch Gap	165		176
	Subtotal	7134		5164
	Total		12,298	

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APPENDIX L

DESCRIPTION OF BIOLOGICAL DEGRADATION STUDIES AT BATTELLE

APPENDIX L

DESCRIPTION OF BIOLOGICAL DEGRADATION STUDIES AT BATTELLE

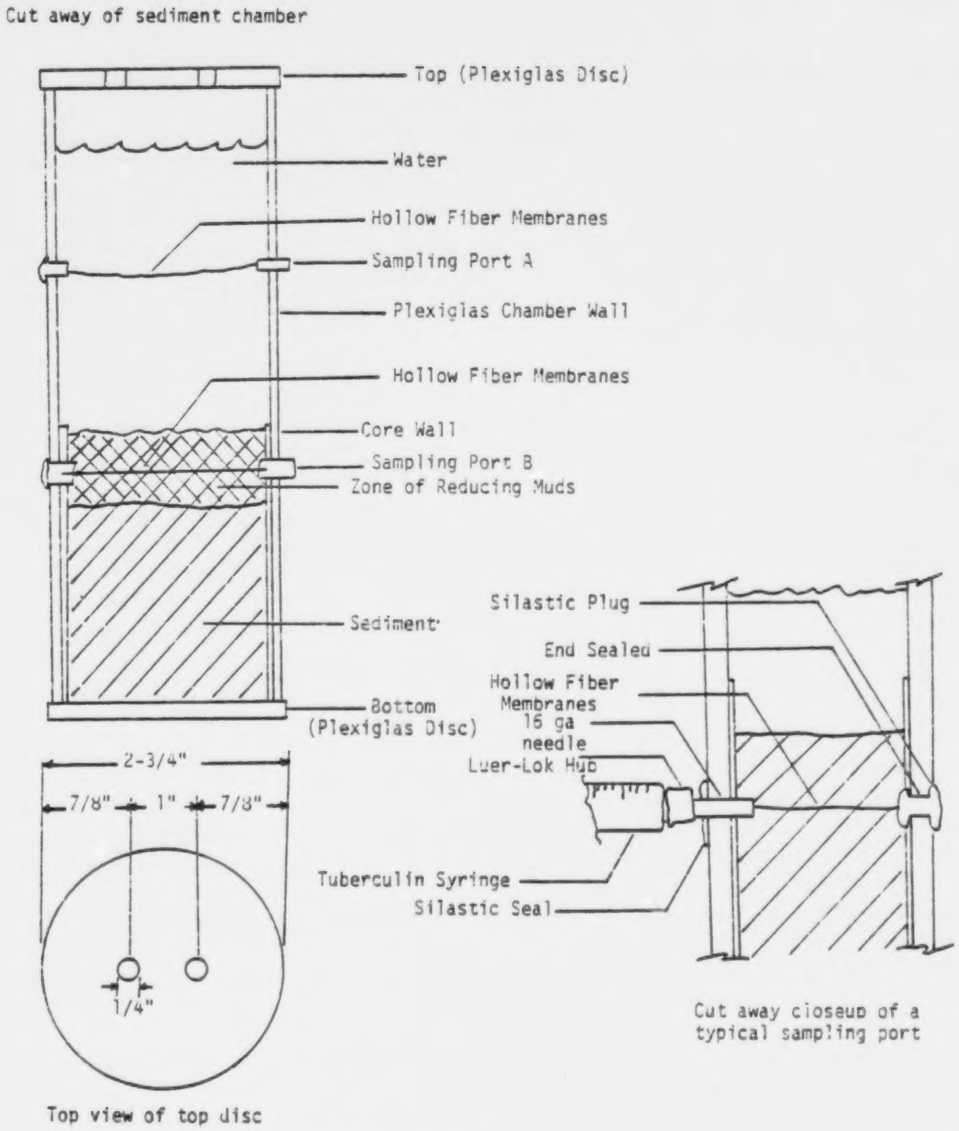
Materials and Methods

Sediment cores were obtained and stored in cellulose acetylbutyrate cylinders sealed with caps at both ends during the James River sampling cruise of June 29, 1977. Cores were of nonuniform lengths, and therefore, presented a problem in maintaining cores as replicate microcosms without causing aerobic conditions while reducing core lengths to uniformity. The solution found was to place cores in plexiglas cylinders having twice the length of the core plus 5 cm (2 in.) to allow equal sediment-water ratios among experimental units.

Figure L.1 shows the sediment-water assembly. To accomplish the sampling of the water column and sediment water, Amicon hollow fiber membranes (30,000 mol. wt. limit) were used. Initially, a hole was drilled in the side of the sediment chamber (through plexiglas cylinder and plastic core wall) at the proper location and a 10 cm (4-in.), 16-gauge needle was passed through the hole to the opposite side of the chamber. The exit hole was then drilled and the needle drawn through. Four hollow fibers were pushed through the needle and the needle removed. One end of the hollow fiber was tripped and sealed with silastic cement; the drill hole was plugged with silastic cement. At the other end, a short 16-gauge needle with Luer-Lok hub was slipped over the hollow fibers and cemented with silastic to the side of the chamber. (The length of the needle was sufficient to pass through both the plexiglas cylinder and core wall.) The ends of the hollow fibers were trimmed and a tuberculin syringe was fixed to the Luer-Lok hub. Reverse-osmosis filtered and autoclaved water was used to make up the water column. The 5 cm (2 in.) at the microcosm top was left empty to allow air sampling and pressure adjustment if methane or H_2S were liberated.

Monitored parameters during equilibration and pretreatment periods included: Ca^{++}, NO_3^--N, and Cl^-. Stability of these parameters, judged by minimal variance and predictable diurnal behavior, was used to determine when ^{14}C-labeled Kepone would be added.

Three replicates of contaminated sediment-water microcosms were selected, based on monitored parameters and similar size, for further experimentation. Three control microcosms were chosen using these same criteria. On November 11, 1977, these microcosms were inoculated with 0.1 ml acetone in the sediment hollow-fiber membrane port. Contaminated microcosms received 12.5 µCi ^{14}C-Kepone in the acetone. After 1 week, monitoring of parameters was resumed and ^{14}C redistribution was examined weekly.


Cut away of sediment chamber

Top view of top disc

Cut away closeup of a typical sampling port

Top (Plexiglas Disc)
Water
Hollow Fiber Membranes
Sampling Port A
Plexiglas Chamber Wall
Hollow Fiber Membranes
Core Wall
Sampling Port B
Zone of Reducing Muds
Sediment
Bottom (Plexiglas Disc)
2-3/4"
7/8"
1"
7/8"
1/4"
Silastic Plug
End Sealed
Hollow Fiber Membranes
16 ga needle
Luer-Lok Hub
Tuberculin Syringe
Silastic Seal

FIGURE L.1. Sediment-Water Assembly

Results

Table L.1 shows total µg (Ca^{++}, Cl^{-}, and NO^{-}) in water and sediment interstitial water during the equilibration and pretreatment periods. During the equilibration period, only Cl^{-} in the water column differed between contaminated and control microcosms. However, by the time of ^{14}C treatment, all parameters differed significantly between contaminated and control microcosms. It is unclear whether these differences are attributable to Kepone or an artifact of heterogeneous microcosm size.

TABLE L.1. MONITORED PARAMETERS IN WATER AND INTERSTITIAL SEDIMENT WATER DURING EQUILIBRATION AND PRETREATMENT PERIODS FOR CONTAMINATED AND CONTROL SEDIMENT-WATER MICROCOSMS

	3 X (S.E.) µg Total					
	Equilibration Period			Pretreatment Period		
	Ca	Cl	NO_3	Ca	Cl	NO_3
Contaminated						
Water	3224	1401*	-	3318*	2580*	1608*
	(295)	(279)		(127)	(109)	(85)
Sediment	3805	2596	-	5292*	3087*	1471*
Water	(441)	(396)		(218)	(207)	(73)
Control						
Water	3338	2289*	-	3894*	1765*	1893*
	(553)	(450)		(53)	(53)	(137)
Sediment	5150	2980	-	6528*	2518*	2835*
Water	(1921)	(423)		(234)	(118)	(155)

Behavior of monitored parameters through time was similar between water and interstitial sediment water. Concentrations of Cl^{-}, NO_3^{-}-N, and Ca^{++} in water were approximately one-half that in sediment water (Figures L.2, L.3 and L.4).* Differences between contaminated and control microcosms occur sporatically through the pretreatment period and cannot yet be easily interpreted.

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* Differences in column height were adjusted by determining the ratio between contaminated and control water and sediment volumes and multiplying concentrations of more dilute conditions (controls) by the ratios for water and sediment, respectively.

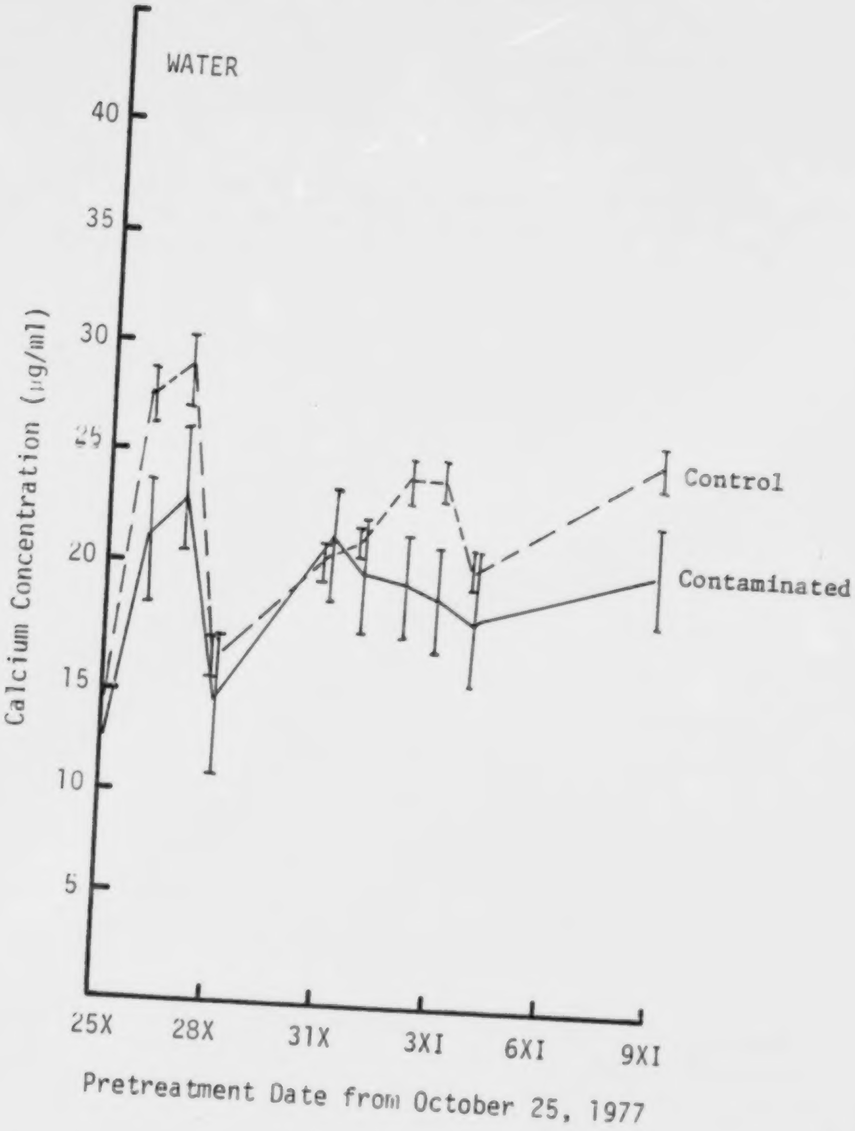


FIGURE L.2. Calcium Concentrations (Adjusted for Differences in Water Volumes) in Water and Sediment Water of Contaminated and Control Microcosms During the Pretreatment Period

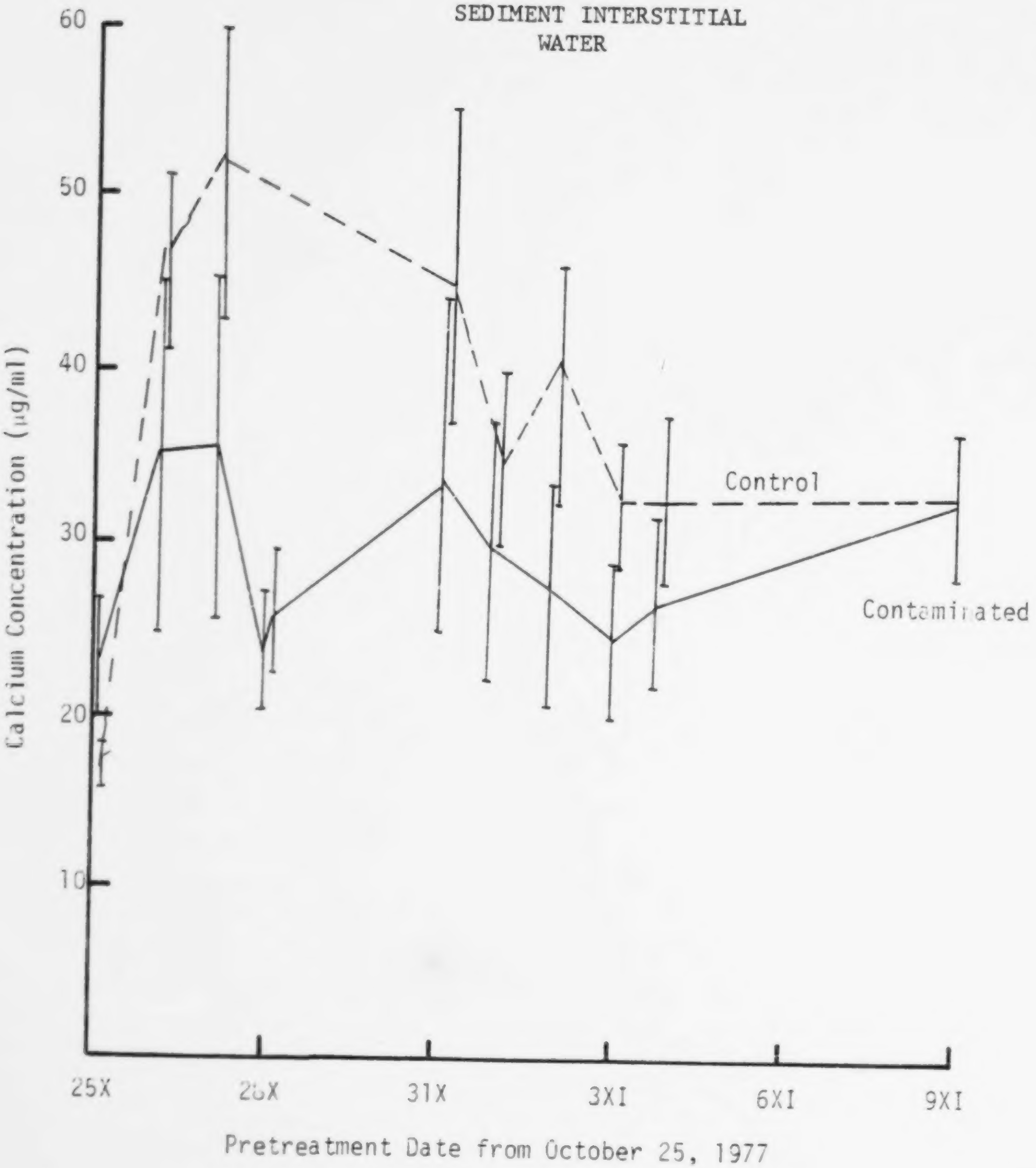


FIGURE L.2. (Continued)

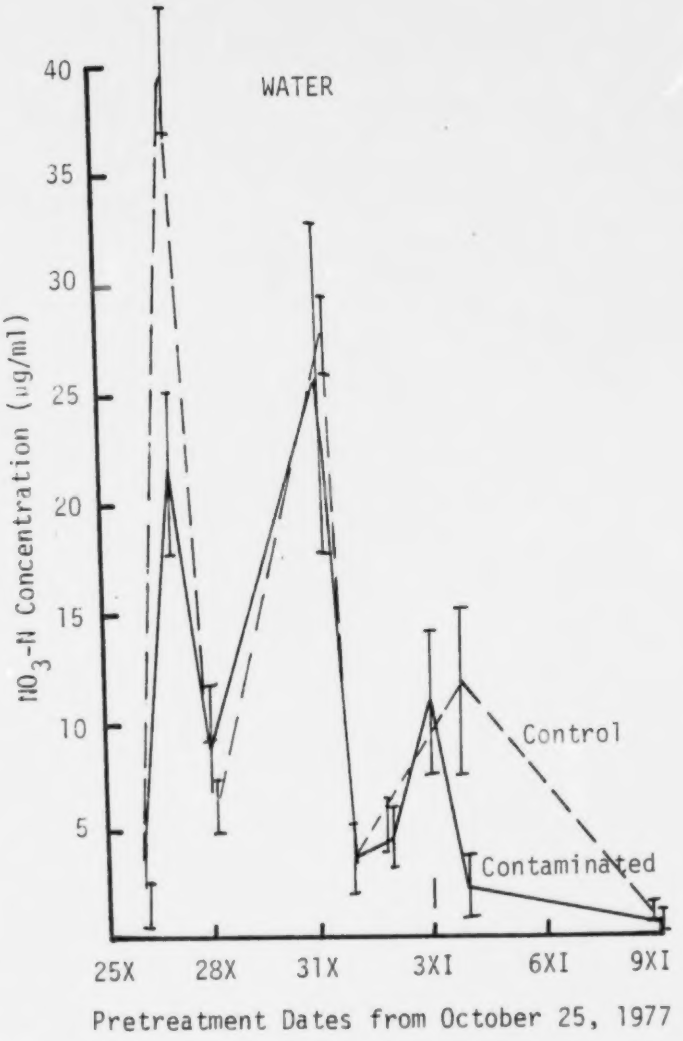


FIGURE L.3. NO$_3$-N Concentrations (Adjusted for Differences in Water Volumes) in Water and Sediment Water of Contaminated and Control Microcosms During the Pretreatment Period

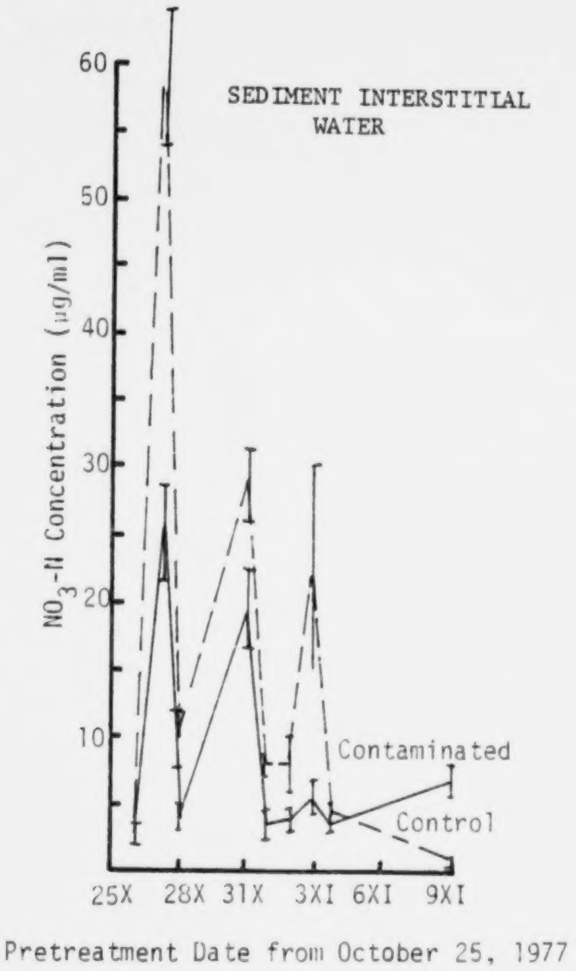


FIGURE L.3. (Continued)

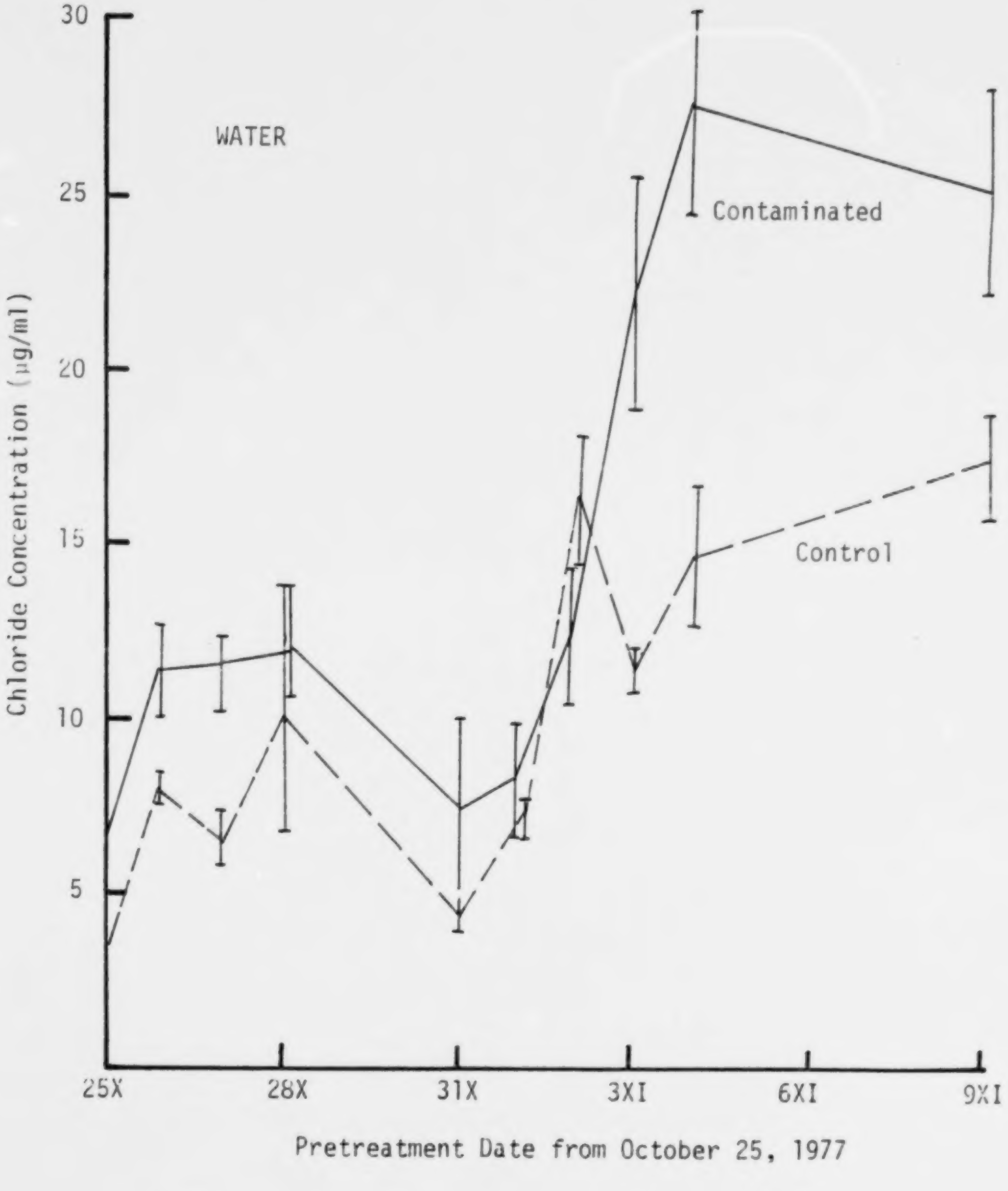


FIGURE L.4. Chloride Concentrations (Adjusted for Differences in Water Volumes) in Water and Sediment Water of Contaminated and Control Microcosms During the Pretreatment Period

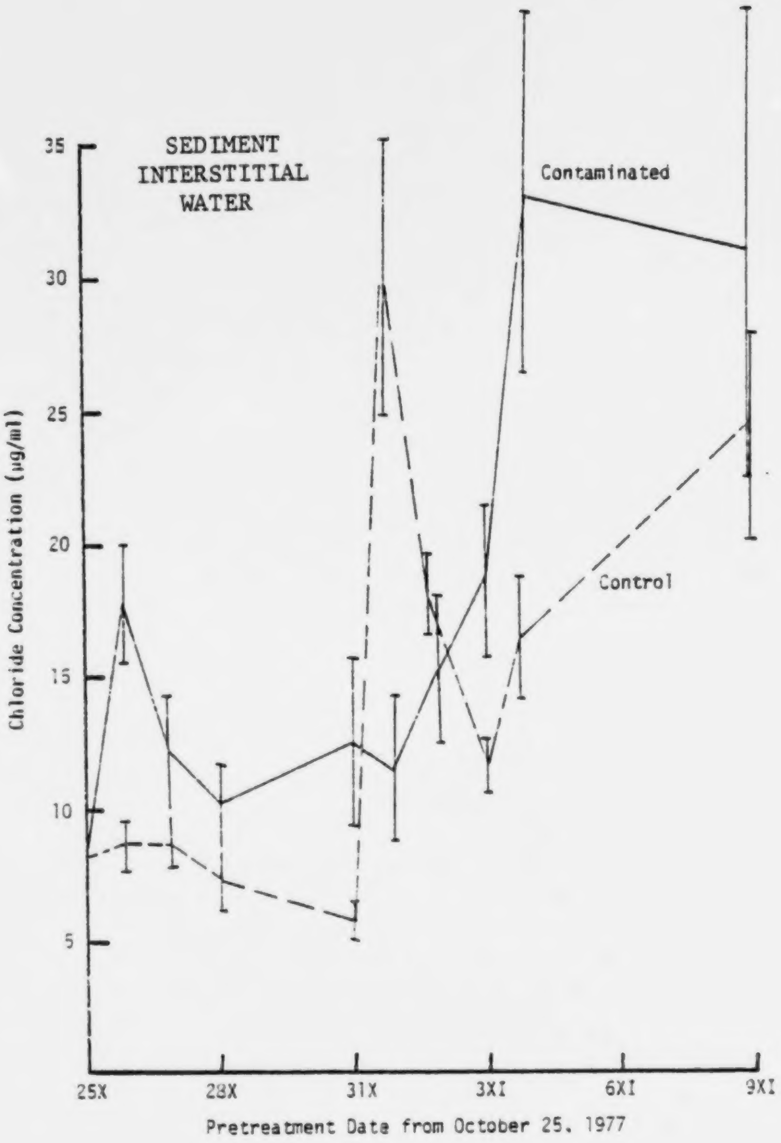


FIGURE L.4. (Continued)

APPENDIX M

MATHEMATICAL SIMULATION OF SEDIMENT AND KEPONE TRANSPORT IN THE TIDAL JAMES RIVER

APPENDIX M

MATHEMATICAL SIMULATION OF SEDIMENT AND KEPONE TRANSPORT IN THE TIDAL JAMES RIVER

A brief description of the sediment and contaminant transport model, FETRA, and mathematical simulation results on sediment and Kepone migration in the tidal James River was presented in Chapter VII. A more detailed discussion is provided in this appendix.

MATHEMATICAL MODEL FORMULATION OF TRANSPORT MODEL, FETRA

The FETRA code consists of the following three submodels: (1) a sediment transport model, (2) a dissolved contaminant transport model, and (3) a particulate contaminant transport model.

Sediment Transport Model

Transport of cohesive sediment (silt and clay), noncohesive sediment (sand), and organic material (that being transported independently with sand, silt and clay) are modeled separately since movements of sediments and adsorption capacity vary significantly. The model includes the effects of:

1. convection and dispersion of materials
2. fall velocity and cohesiveness
3. deposition on the river bed
4. resuspension from the river bed (bed erosion and armoring)
5. tributaries

Sediment mineralogy and water quality effects are implicitly included through the above mentioned effects 2, 3 and 4.

Governing Equations--

The governing equation of sediment transport for the three-dimensional case is:

$$\frac{\partial C_j}{\partial t} + \frac{\partial}{\partial x}(UC_j) + \frac{\partial}{\partial y}(VC_j) + \frac{\partial}{\partial z}\left\{(W - W_{sj})C_j\right\}$$

$$= \frac{\partial}{\partial x}\left(\varepsilon_{xj}\frac{\partial C_j}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_{y_j}\frac{\partial C_j}{\partial y}\right) + \frac{\partial}{\partial z}\left(\varepsilon_{z_j}\frac{\partial C_j}{\partial z}\right) \qquad (1)$$

where

Cj = concentration of sediment of j^{th} type (weight of sediment per unit volume of water)

t = time

U = velocity component of longitudinal (x) direction

V = velocity component of lateral (y) direction

W = velocity component of vertical (z) direction

W_{sj} = fall velocity of sediment particle of j^{th} type

x, y, z = longitudinal, lateral and vertical direction in Cartesian coordinates, respectively

$\varepsilon_{xj}, \varepsilon_{yj}, \varepsilon_{zj}$ = diffusion coefficients of longitudinal, lateral and vertical directions for j^{th} sediment type.

Boundary conditions are:

$$(W - W_{sj})C_j - \varepsilon_{zj}\frac{\partial C_j}{\partial z} = 0 \qquad \text{at } z = h \tag{2}$$

$$(1-\gamma)\, W_{sj}C_j + \varepsilon_{zj}\frac{\partial C_j}{\partial z} = S_{D_j} - S_{R_j} \qquad \text{at } z = 0 \tag{3}$$

$$\frac{\partial C_j}{\partial y} = 0 \qquad \text{at } y = 0 \text{ and } B \tag{4}$$

where

B = width of the river

S_{D_j} = sediment deposition rate per unit bed surface area for j^{th} sediment type

S_{R_j} = sediment erosion rate per unit bed surface area for j^{th} sediment type

γ = coefficient, i.e., probability that particle settling to the bed is deposited.

In this study, γ was assumed to be unity, that is, for the same flow condition all suspended matter settling on the river bed stays on the river bed without returning to the flow. It is also assumed that the vertical flow velocity, W, is negligible.

Let

$$C_j = \bar{C}_j + c''_j \tag{5}$$

$$U = \bar{U} + u'' \qquad (6)$$

$$V = \bar{V} + v'' \qquad (7)$$

$$\frac{\partial c_j''}{\partial x} = \frac{\partial c_j''}{\partial y} = \frac{\partial W_{s_j}}{\partial z} = 0 \qquad (8)$$

where

$\bar{C}_j, \bar{U}, \bar{V}$ = depth averaged values of concentration of sediment for j^th^ type, longitudinal velocity, and lateral velocity, respectively

c_j'', u'', v'' = fluctuations from the depth averaged values of concentration of sediment of j^th^ type, longitudinal velocity, and lateral velocity, respectively.

By substituting the above expressions into Equation (1) and integrating it over the entire river depth, this equation becomes:

$$\begin{aligned}
&\bar{C}_j \left\{\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}(\bar{U}h) + \frac{\partial}{\partial y}(\bar{V}h)\right\} - (\bar{C}_j + c_j'')\Big|_{z=h} \left\{\frac{\partial h}{\partial t} + (\bar{U} + u'')\Big|_{z=h} \frac{\partial h}{\partial x}\right. \\
&\quad \left. + (\bar{V} + v'')\Big|_{z=h} \frac{\partial h}{\partial y}\right\} + \left\{W_{s_j}(\bar{C}_j + c_j'')\Big|_{z=h} + \varepsilon_{z_j} \frac{\partial(\bar{C}_j + c_j'')}{\partial z}\Big|_{z=h}\right\} \\
&\quad = - h\left(\frac{\partial \bar{C}_j}{\partial t} + \bar{U}\frac{\partial \bar{C}_j}{\partial y} + \bar{V}\frac{\partial \bar{C}_j}{\partial y}\right) + h\frac{\partial}{\partial x}\left(\varepsilon_{x_j} \frac{\partial \bar{C}_j}{\partial x}\right) + h\frac{\partial}{\partial y}\left(\varepsilon_{y_j} \frac{\partial \bar{C}_j}{\partial y}\right) \\
&\quad - \frac{\partial}{\partial x}\int_o^h u''c_j''dz - \frac{\partial}{\partial y}\int_o^h v''c_j''dz - \left\{W_{s_j}(\bar{C}_j + c_j'')\Big|_{z=0}\right. \\
&\quad \left. + \varepsilon_{z_j} \frac{\partial(\bar{C}_j + c_j'')}{\partial z}\Big|_{z=0}\right\}
\end{aligned} \qquad (9)$$

The equation of continuity, the kinetic water surface boundary condition and Equation (2) make the left side of Equation (9) zero. As in the Boussinesq diffusion coefficient concept, let:

$$\int_o^h u''c_j''dz = (\overline{u''c_j''})h = - hD_{x_j} \frac{\partial \bar{C}_j}{\partial x} \qquad (10)$$

and

$$\int_o^h v''c_j''dz = (\overline{v''c_j''})h = - hD_{y_j} \frac{\partial \bar{C}_j}{\partial y} \qquad (11)$$

where D_{xj} and D_{yj} equal the dispersion coefficients of x and y directions for j^{th} sediment type. Hence Equations (2), (3), (9), (10), and (11) yield the following final expression of sediment transport:

$$\frac{\partial \bar{C}_j}{\partial t} + \left(\bar{U} - \frac{D_{x_j}}{h}\frac{\partial h}{\partial x}\right)\frac{\partial \bar{C}_j}{\partial x} + \left(\bar{V} - \frac{D_{y_j}}{h}\frac{\partial h}{\partial y}\right)\frac{\partial \bar{C}_j}{\partial y}$$

$$= \frac{\partial}{\partial x}\left(K_{x_j}\frac{\partial \bar{C}}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{y_j}\frac{\partial \bar{C}}{\partial y}\right) + \frac{S_{R_j}}{h} - \frac{S_{D_j}}{h} \qquad (12)$$

where

$$K_{x_j} = \varepsilon_{x_j} + D_{x_j}$$

$$K_{y_j} = \varepsilon_{y_j} + D_{y_j}$$

The finite element method was used to solve Equations (4) and (12).

Erosion and Deposition of Noncohesive Sediments (Sand)--

Erosion and deposition of noncohesive sediments are affected by the amount of sediment the flow is capable of carrying. For example, if the amount of sand being transported is less than the flow can carry for given hydrodynamic conditions, the river will scour sediment from the stream bed to increase the sediment transport rate. This occurs until the actual sediment transport rate becomes equal to the carrying capacity of the flow or until the available bed sediments are all scoured, whichever occurs first. Conversely, the river deposits sand if its actual sediment transport rate is above the flow's capacity to carry sediment. DuBoy's formula is used to estimate the flow capacity, Q_s, which is then compared with the actual amount of sand, Q_{sa}, being transported in the river water. Hence:

$$S_{R_j} = \frac{Q_s - Q_{sa}}{A} \qquad (13)$$

$$S_{D_j} = \frac{Q_{sa} - Q_s}{A} \qquad (14)$$

where

A = the river bed surface area

Erosion and Deposition of Cohesive Sediments (Silt and Clay)--

Sediment erosion and deposition rates, S_{Rj} and S_{Dj}, are also evaluated separately for each sediment size fraction because erosion and deposition characteristics are significantly different for cohesive and noncohesive sediments. Since only Partheniades (1962) and Krone (1962) formulas for erosion and deposition rates, respectively, are presently available, these formulas were adopted in this study:

$$S_{R_j} = \left(M_j \frac{\tau_b}{\tau_{cR_j}} - 1 \right) \tag{15}$$

$$S_{D_j} = \frac{2W_{sj}C_j}{h} \left(1 - \frac{\tau_b}{\tau_{cD_j}} \right) \tag{16}$$

where

M_j = erodibility coefficient for sediment of j^{th} type fraction

τ_b = bed shear stress

τ_{cD_j} = critical shear stress for sediment deposition for j^{th} sediment type fraction

τ_{cR_j} = critical shear stress for sediment erosion for j^{th} sediment type fraction.

Values of M_j, τ_{cD_j} and τ_{cR_j} must be determined by field and/or laboratory tests for a particular river regime. These values for the Columbia River (Washington) and the Clinch River (Tennessee) were reported in recent mathematical simulation studies concerning sediment and radionuclide transport in these two rivers (Onishi, 1977a; Onishi, 1977b). The availability of bed sediments to be resuspended was also examined to determine the actual amount of sediment erosion.

When the fall velocity, W_{sj}, depends on sediment concentration and no aggregation occurs, the fall velocity may be assumed (Krone, 1962):

$$W_{sj} = K_j C_j^{4/3} \tag{17}$$

where

K_j = an empirical constant depending on the sediment type.

Erosion and Deposition of Organic Materials--

Recent studies (Shupe and Dawson, 1977; Huggett et al., 1977) revealed the Kepone is not only adsorbed by inorganic suspended sediment (mainly cohesive sediments) but also adsorbed by organic matter. Unfortunately, there have not been enough studies on transport characteristics of organic materials. Since the mechanics of erosion and deposition of organic matter are somewhat similar to those of cohesive fine sediment, Equations (15) and (16) were utilized for this case. The selection of the values of W_{sj}, M_j, τ_{cDj} and τ_{cRj} should reflect the characteristics of these materials, e.g., density, size, cohesiveness, compatibility, etc.

Dissolved Contaminant Transport Model

In this study, it was assumed that the association of dissolved contaminant (such as dissolved Kepone) with suspended sediments (both organic and inorganic matter) is the primary mechanism of Kepone uptake. The model includes the effects of:

1. convection and dispersion of dissolved contaminant within the river
2. adsorption (uptake) of dissolved contaminant by sediments (cohesive and noncohesive inorganic sediments and organic matter) or desorption from the sediments into water
3. chemical and biological decay of contaminant
4. tributaries. (Contaminant contributions from wastewater discharges, overland runoff flow, fallout and ground water to a river system may be treated as a part of tributary contributions.)

Effects of water quality (e.g., pH, water temperature, salinity, etc.) and sediment characteristics, (e.g., clay minerals), are taken into account through changes in the distribution (or partition) coefficient, K_{d_j}.

The governing equation of dissolved Kepone transport for the three-dimensional case is:

$$\begin{aligned}\frac{\partial G_w}{\partial t} &+ \frac{\partial}{\partial x}(UG_w) + \frac{\partial}{\partial y}(VG_w) + \frac{\partial}{\partial z}(WG_w)\\ &= \frac{\partial}{\partial x}\left(\varepsilon_{x_w}\frac{\partial G_w}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_{y_w}\frac{\partial G_w}{\partial y}\right) + \frac{\partial}{\partial z}\left(\varepsilon_{z_w}\frac{\partial G_w}{\partial z}\right)\\ &- \lambda G_w - \sum_j K_j(K_{d_j}C_jG_w - K_{p_j}C_jG_j) \qquad (18)\end{aligned}$$

In addition to the previously defined symbols:

K_{d_j} = distribution (or partition) coefficient between dissolved contaminant and particulate contaminant associated with jth sediment

K_j = mass transfer rate of contaminant for jth sediment

K_{p_j} = nondimensional coefficient: equal unity if contaminant adsorption or desorption associated with j^{th} sediment occurs ($K_{d_j} = 1$); equal zero if neither contaminant adsorption nor desorption associated with j^{th} sediment occurs ($K_{d_j} = 0$)

G_j = particulate contaminant concentration associated with j^{th} sediment (weight or contaminant per unit weight of sediment)

G_w = dissolved contaminant concentration (weight of contaminent per unit volume of water)

$\varepsilon_{x_w}, \varepsilon_{y_w}, \varepsilon_{z_w}$ = longitudinal, lateral and vertical diffusion coefficients for dissolved contaminant

λ = chemical and biological decay rate of contaminant (nil for Kepone)

Distribution coefficient, K_{d_j}, is defined by:

$$K_{d_j} = \frac{f_{s_j}/M_j}{f_w/V_w} = \frac{f_{s_j}}{f_w C_j} \tag{19}$$

where

f_{s_j} = fraction of contaminant sorbed by j^{th} sediment

f_w = fraction of contaminant left in solution

M_j = weight of j^{th} sediment

V_w = volume of water

$$\frac{f_{s_j}}{f_w} = \frac{C_j G_j}{G_w}$$

Hence Equation (19) may be rewritten as:

$$G_j = K_{d_j} G_w \tag{20}$$

The adsorption of contaminant by sediments or desorption from the sediments is assumed to occur toward an equilibrium condition with the mass transfer rate, K_j, if the particulate contaminant concentration differs from its equilibrium values as expressed in Equation (20).

The boundary conditions for dissolved pollutant transport are:

$$WG_w - \varepsilon_{z_w} \frac{\partial G_w}{\partial z} = 0 \qquad \text{at } z = h \tag{21}$$

$$\frac{\partial G_w}{\partial z} = 0 \qquad \text{at } z = 0 \tag{22}$$

$$\frac{\partial G_w}{\partial y} = 0 \qquad \text{at } z = 0 \text{ and } B \tag{23}$$

Let:

$$G_w = \bar{G}_w + G''_w \tag{24}$$

$$\frac{\partial G''_w}{\partial x} = \frac{\partial G''_w}{\partial y} = 0 \tag{25}$$

where

$\bar{G}_w$ = depth averaged value of pollutant concentration

G''_w = fluctuation from the depth averaged value of pollutant concentration

By substituting the above expressions, together with those in Equations (5) through (8), into Equation (18) and integrating it over the entire river depth, Equation (18) becomes:

$$\begin{aligned}
&\bar{G}_w \left\{ \frac{\partial h}{\partial t} + \frac{\partial}{\partial x}(\bar{U}h) + \frac{\partial}{\partial y}(\bar{V}h) \right\} - (\bar{G}_w + G''_w)\Big|_{z=h} \left\{ \frac{\partial h}{\partial t} + (\bar{U} + u'')\Big|_{z=h} \frac{\partial h}{\partial x} \right. \\
&\left. + (\bar{V} + v'')\Big|_{z=h} \frac{\partial h}{\partial y} \right\} + \left\{ (\bar{W} + w'')(\bar{G}_w + G''_w)\Big|_{z=h} - \varepsilon_{z_w} \frac{\partial}{\partial z}(\bar{G}_w + G''_w)\Big|_{z=h} \right\} \\
&+ \varepsilon_{z_w} \frac{\partial}{\partial z}(\bar{G}_w + G''_w)\Big|_{z=o} \\
&= -h\left(\frac{\partial \bar{G}_w}{\partial t} + \bar{U}\frac{\partial \bar{G}_w}{\partial x} + \bar{V}\frac{\partial \bar{G}_w}{\partial y}\right) + D_{x_w}\frac{\partial h}{\partial x}\frac{\partial \bar{G}_w}{\partial x} + D_{y_w}\frac{\partial h}{\partial y}\frac{\partial \bar{G}_w}{\partial y} \\
&+ h\frac{\partial}{\partial x}\left\{(\varepsilon_{x_w} + D_{x_w})\frac{\partial \bar{G}_w}{\partial x}\right\} + h\frac{\partial}{\partial y}\left\{(\varepsilon_{y_w} + D_{y_w})\frac{\partial \bar{G}_w}{\partial y}\right\} \\
&- \lambda h \bar{G}_w - h \sum_j K_j \bar{C}_j (K_{d_j} \bar{G}_w - K_{p_j} G_j)
\end{aligned} \tag{26}$$

where D_{x_w} and D_{y_w} are dispersion coefficients of x and y directions defined by:

$$\int_o^h u''G_w'' \, dz = - h \, D_{x_w} \frac{\partial \bar{G}_w}{\partial x} \qquad (27)$$

$$\int_o^h V''G_w''dz = - h \, D_{y_w} \frac{\partial \bar{G}_w}{\partial y} \qquad (28)$$

The equation of continuity, the kinetic water surface boundary condition and boundary conditions shown in Equations (21) and (22) then make the left side of Equation (26) zero. Hence, the final transport equation of dissolved pollutant is:

$$\frac{\partial \bar{G}_w}{\partial t} + (\bar{U} - \frac{D_{x_w}}{h} \frac{\partial h}{\partial x}) \frac{\partial \bar{G}_w}{\partial x} + (\bar{V} - \frac{D_{y_w}}{h} \frac{\partial h}{\partial y}) \frac{\partial \bar{G}_w}{\partial y}$$

$$= \frac{\partial}{\partial x} (k_{x_w} \frac{\partial \bar{G}_w}{\partial x}) + \frac{\partial}{\partial y} (k_{y_w} \frac{\partial \bar{G}_w}{\partial y}) - (\lambda + \sum_j K_j K_{d_j} \bar{C}_j) \bar{G}_w$$

$$+ \sum_j K_j K_{P_j} \bar{C}_j G_j \qquad (29)$$

where

$$k_{x_w} = E_{x_w} + D_{x_w}$$

$$k_{y_w} = E_{y_w} + D_{y_w}$$

The boundary conditions for this equation are those in Equation (23).

Particulate Contaminant Transport Model

The transport model of pollutants (such as Kepone in this study) attached to sediments is solved separately for those adsorbed by cohesive and non-cohesive sediments, and organic material (that being transported independently with the inorganic sediments). This model also includes the effects of:

1. convection and dispersion of particulate pollutant
2. adsorption (uptake) of dissolved pollutant by sediments or desorption from sediments into water
3. chemical and biological decay of pollutant

4. deposition of particulate pollutant on the river bed or resuspension from the river bed

5. tributaries. (Pollutant contributions from wastewater discharges, overland runoff flow, fallout and ground water to a river system may be treated as a part of the tributary contributions.)

As in the transport of sediments and dissolved pollutant, the three-dimensional transport equation for contaminants adsorbed by the j^{th} sediment type (cohesive sediment, noncohesive sediment or organic materials) may be expressed as:

$$\frac{\partial C_j G_j}{\partial t} + \frac{\partial}{\partial x}(UC_j G_j) + \frac{\partial}{\partial y}(VC_j G_j) + \frac{\partial}{\partial z} \left\{(W - W_{s_j})C_j G_j\right\} = \frac{\partial}{\partial x}\left(\varepsilon_{x_j} \frac{\partial C_j G_j}{\partial x}\right)$$

$$+ \frac{\partial}{\partial y}\left(\varepsilon_{y_j} \frac{\partial C_j G_j}{\partial y}\right) + \frac{\partial}{\partial z}\left(\varepsilon_{z_j} \frac{\partial C_j G_j}{\partial z}\right) - \lambda C_j G_j - K_j (K_{p_j} C_j G_j$$

$$- K_{d_j} C_j G_w) \tag{30}$$

where the Kepone concentration, G_j, is assumed to be independent of z (Onishi, 1977a; Onishi, 1977b). All symbols in Equation (30) were previously defined. Noting Equations (2), (3), and (4), boundary conditions for this case become:

$$(W - W_{s_j})\, G_j G_j - \varepsilon_{z_j} \frac{\partial C_j G_j}{\partial z} = G_j \left\{(W-W_{s_j})\, C_j - \varepsilon_{z_j} \frac{\partial C_j}{\partial z}\right\} = 0 \quad \text{at } z = h \tag{31}$$

$$(1-\gamma)\ W_{s_j} C_j G_j + \varepsilon_{z_j} \frac{\partial C_j G_j}{\partial z} = G_j S_{D_j} - G_{B_j} S_{R_j} \quad \text{at } z = 0 \tag{32}$$

$$\frac{\partial C_j G_j}{\partial y} = C_j \frac{\partial G_j}{\partial y} + G_j \frac{\partial C_j}{\partial y} = C_j \frac{\partial G_j}{\partial y} = 0 \quad \text{Hence } \frac{\partial G_j}{\partial y} = 0 \quad \text{at } y = 0 \text{ and } B \tag{33}$$

where G_{B_j} is a particulate contaminant concentration associated with j^{th} sediment in river bed. Equation (34) is derived by i) substituting Equations (5) through (8) into Equation (30), ii) integrating it over the river depth, iii) then subtracting Equation (9) multiplied by G_j from the resulting equation, and iv) substituting the boundary conditions, Equations (31) and (32)

$$\frac{\partial G_j}{\partial t} + \left\{\bar{U} - \frac{2\varepsilon_{x_j}}{\bar{C}_j} \frac{\partial \bar{C}_j}{\partial x} - \frac{D_{x_j}}{\bar{C}_j} \frac{\partial \bar{C}_j}{\partial x} + \frac{\varepsilon_{x_j}}{\bar{C}_j h} \frac{\partial h}{\partial x} \left(c''_j \big|_{z = h}\right)\right\} \frac{\partial G_j}{\partial x}$$

$$+ \left\{\bar{V} - \frac{2\varepsilon_{y_j}}{\bar{C}_j} \frac{\partial \bar{C}_j}{\partial y} - \frac{D_{y_j}}{\bar{C}_j} \frac{\partial \bar{C}_j}{\partial y} + \frac{\varepsilon_{y_j}}{\bar{C}_j h} \frac{\partial h}{\partial y} \left(c''_j \big|_{z = h}\right)\right\} \frac{\partial G_j}{\partial y}$$

$$= \frac{\partial}{\partial x}\left(\varepsilon_{x_j}\frac{\partial G_j}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_{y_j}\frac{\partial G_j}{\partial y}\right) - \left(\frac{S_{R_j}}{\bar{C}_j h} + \lambda + K_j\ K_{Pj}\right) G_j$$

$$+ \left(K_j\ K_{d_j}\ G_w + \frac{G_{B_j} S_{R_j}}{\bar{C}_j h}\right) \qquad (34)$$

Since the two terms containing c" in the above equation are at least one order of magnitude smaller than the rest of the terms, these two terms may be deleted. Hence, the final expression becomes:

$$\frac{\partial G_j}{\partial t} + \left\{\bar{U} - \frac{2\varepsilon_{x_j}}{\bar{C}_j}\frac{\partial \bar{C}_j}{\partial x} - \frac{D_{x_j}}{\bar{C}_j}\frac{\partial \bar{C}_j}{\partial x}\right\}\frac{\partial G_j}{\partial x} + \left\{\bar{V} - \frac{2\varepsilon_{y_j}}{\bar{C}_j}\frac{\partial \bar{C}_j}{\partial y} - \frac{D_{y_j}}{\bar{C}_j}\frac{\partial \bar{C}_j}{\partial y}\right\}\frac{\partial G_j}{\partial y}$$

$$= \frac{\partial}{\partial x}\left(\varepsilon_{x_j}\frac{\partial G_j}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_{y_j}\frac{\partial G_j}{\partial y}\right) - \left(\frac{S_{R_j}}{\bar{C}_j h} + \lambda + K_j\ K_{Pj}\right) G_j$$

$$+ \left(K_j\ K_{d_j}\ G_w + \frac{G_{B_j} S_{R_j}}{\bar{C}_j h}\right) \qquad (35)$$

The boundary conditions for this case are those expressed in Equation (33).

Finite Element Method

High-speed digital computers have enabled engineers to employ various numerical discretization techniques for approximating solutions to complex mathematical equations. The finite element method is one such technique (Desai, 1972) and has recently gained popularity for solving both linear and nonlinear partial differential equations. Because of its increased solution accuracy and ready accommodation to various boundary geometrics (e.g., Onishi, 1977a; Onishi, 1977b; Norton et al., 1973; Brandstetter et al., 1976) this method was used for this study. The finite element solution technique with the Galerkin weighted residual method is used to solve Equations (12), (29) and (35) with the boundary conditions of Equations (4), (23) and (33).

The flow domain is divided into a series of triangular elements interconnected at node points. Six nodes are associated with each triangle, three at the vertices called corner nodes and three on the mid-sides called mid-side nodes. A quadratic approximation is made for the sediment and contaminant concentrations within each element. Either linear or quadratic interpolation is used for the variation of flow depth and velocity within an element. For the present Kepone study, the linear approximation of depth and velocity was used. The computer program is written in FORTRAN IV language to implement the model for a CDC 7600 computer. A more detailed description of the FETRA code programming is discussed in Onishi et al. (1976).

VERIFICATION OF BASIC COMPUTATIONAL SCHEME OF FETRA MODEL

Prior to the application of the FETRA code to the present tidal James River study, the accuracy and convergence of the numerical solutions calculated by the finite element sediment and contaminant transport model, FETRA, had been evaluated to confirm the validity of the basic computational scheme of the model. This verification involved solving equations by the FETRA code and comparing the resulting numerical solutions with known analytical solutions to the problems.

Unfortunately, the general unsteady two-dimensional convection-diffusion equation with decay and source (or sink) terms [e.g., Equations (29) and (35)] does not have known analytical solutions. Therefore, some simplified special cases were used for the analysis. The following four cases were selected as test cases.

Case 1

In this case the following one-dimensional steady convection-diffusion equation with a source term was solved:

$$U\frac{dC}{dx} = \varepsilon_x \frac{d^2C}{dx^2} + \beta \tag{36}$$

with the boundary conditions of:

$$\left.\begin{aligned} C &= C_o \quad \text{at } x = 0 \\ \frac{dC}{dx} &= 0 \quad \text{at } x = \ell \end{aligned}\right. \tag{37}$$

An analytical solution to this problem is:

$$C = C_o + \frac{\beta \varepsilon_x}{U^2} \left[\exp\left(-\frac{U\ell}{\varepsilon_x}\right) - \exp\left[-\frac{U}{\varepsilon_x}(\ell - x)\right] \right] + \frac{\beta x}{U} \tag{38}$$

Figure M.1 shows computer results and the analytical solution, assuming:

$U = 5.0$, $\varepsilon_x = 0.2$, $\beta = 2.0$, $C_o = 1.0$ and $\ell = 1.0$

An excellent agreement between these two solutions was obtained in this case.

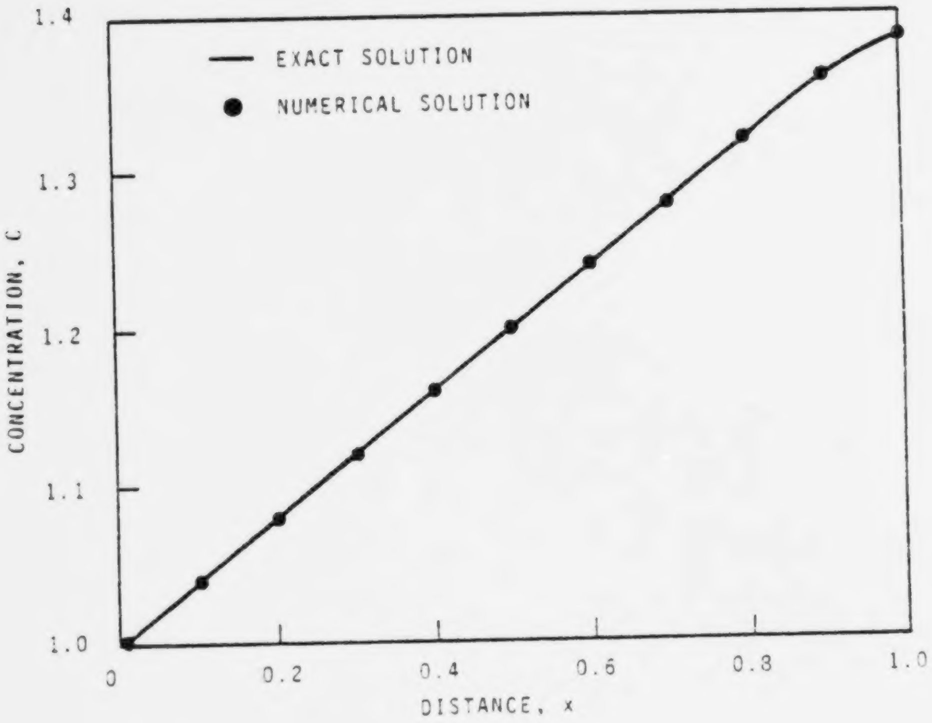


FIGURE M.1. Comparison of Numerical Solution with Analytical Solution to One-Dimensional Steady Convection-Diffusion Equation with a Source Term

Case 2

In this case, the following convection-diffusion equation with a decay term was solved with the same boundary conditions as Case 1.

$$U\frac{dC}{dx} = \varepsilon_x\frac{d^2C}{dx^2} - \alpha C$$

With $U = 5.0$, $\varepsilon_x = 0.2$, $\alpha = 10.0$, $C_o = 1.0$ and $\ell = 1.0$, an excellent agreement between these two solutions was obtained, as shown in Figure M.2.

Case 3

In this case, convergence of a time-dependent, one-dimensional solution to a steady-state solution was tested. The governing equation was:

$$\frac{\partial C}{\partial t} = \varepsilon_x\frac{\partial^2 C}{\partial x^2} - \alpha C \qquad (39)$$

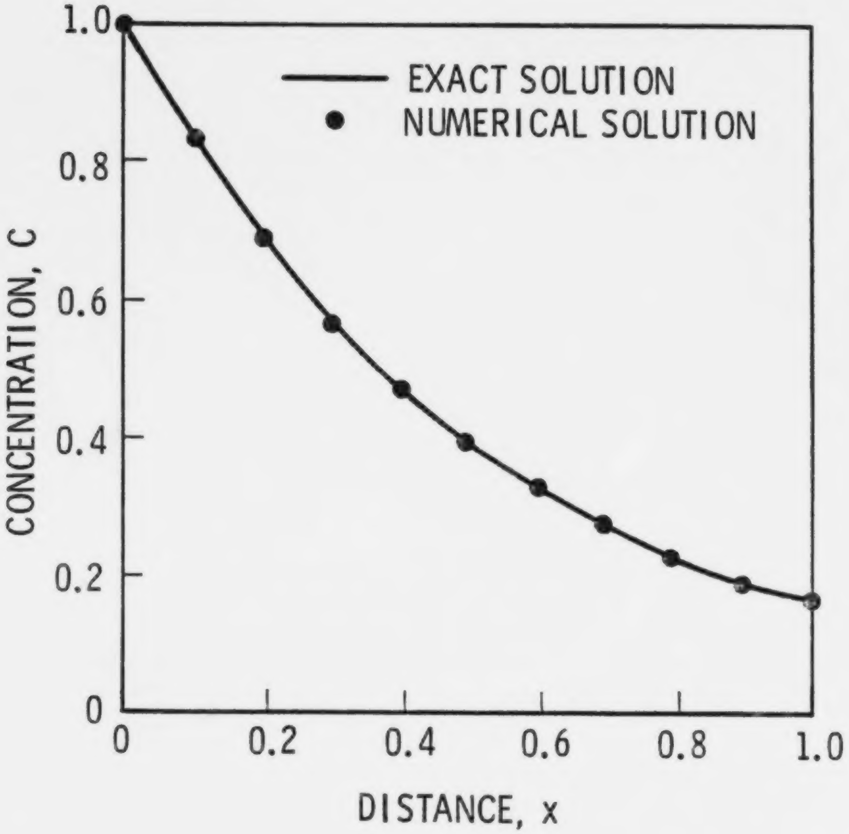


FIGURE M.2. Comparison of Numerical Solution with Analytical Solution of One-Dimensional Steady Convection-Diffusion Equation with a Decay Term

with the following conditions:

$$
\begin{array}{llll}
C = 0 & \text{in} \quad 0 \le x \le \ell & \text{at} & t = 0 \\
C = C_o & \text{at} \quad x = 0 & \text{at} & t > 0 \\
\frac{\partial C}{\partial t} = 0 & \text{at} \quad x = \ell & \text{for all} & t
\end{array}
\qquad (40)
$$

Assuming $\varepsilon_x = 0.2$, $\alpha = 1.0$, $C_o = 1.0$ and $\ell = 1.0$, solutions are plotted in Figure M.3, together with steady analytical and numerical solutions of the following equation:

$$\varepsilon_x \frac{\partial^2 C}{\partial x^2} - \alpha C = 0 \qquad (41)$$

As shown in Figure M.3, there is convergence to the steady exact solution of Equation (41). For runs with time t greater than 4.0, the numerical solutions coincide with the analytical solution. The steady-state numerical solution also agrees well with the exact solution.

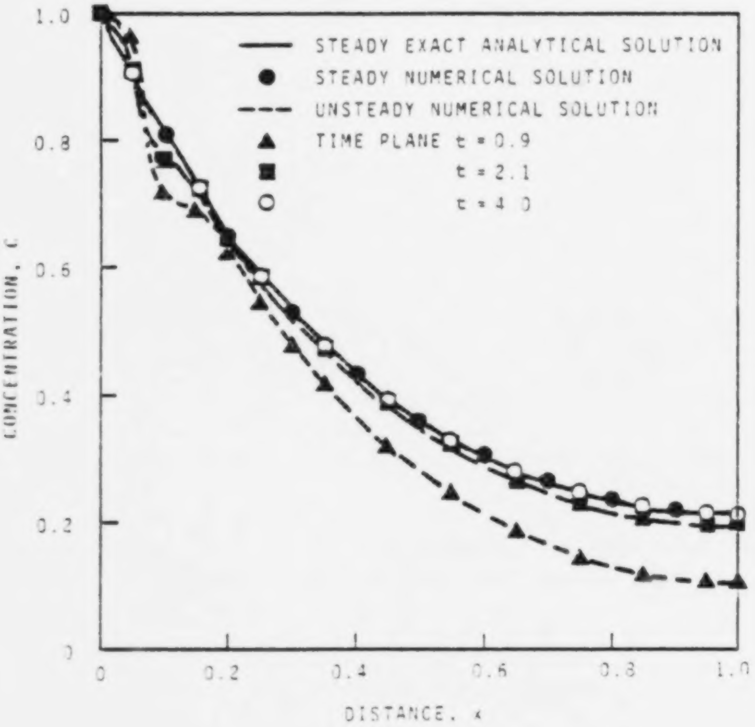


FIGURE M.3. Convergence of Unsteady-State One-Dimensional Diffusion Equation to Steady-State Solution

Case 4

The following two-dimensional equation was solved numerically and computed results were compared with an analytical solution:

$$\varepsilon_x \frac{\partial^2 C}{\partial x^2} + \varepsilon_y \frac{\partial^2 C}{\partial y^2} = 0 \qquad (42)$$

with boundary conditions of:

$$\begin{aligned} C &= 0 && \text{at} \quad x = 0 \\ C &= 0 && \text{at} \quad x = \ell \\ C &= 0 && \text{at} \quad y = 0 \\ C &= C_o \sin(\tfrac{\pi x}{\ell}) && \text{at} \quad y = \ell \end{aligned} \tag{43}$$

where $\varepsilon_x = \varepsilon_y = \ell = 1.0$ and $C_o = 10$. The analytical solution for this case is:

$$C(x,y) = 0.866 \sinh(\pi y) \sin(\pi x) \tag{44}$$

The computer results and analytical solutions are shown in Figure M.4. Numbers in the figure are values of concentration C. Since the solutions are symmetric with respect to x = 0.5, computer results are given in the region of $0.5 \leq x \leq 1.0$, and analytical solutions are plotted in the region of $0 \leq x < 0.5$. Comparison of these results reveals that there is an excellent agreement between the computed and analytical solutions.

As illustrated in Figures M.1 through M.4 the agreements of the model solutions and the exact solutions were excellent. These results confirm the validity of the basic numerical computation scheme of the transport model, FETRA.

COMPUTER SIMULATION RESULTS

The FETRA code was employed in combination with the EXPLORE code to calculate Kepone transport in the James River estuary. The model was applied to an 86-km reach between City Point (River Kilometer 123) and Burwell Bay (River Kilometer 37), as shown in Figure M.5.

Both one (longitudinal) and two (longitudinal and lateral) dimensional simulation was attempted. However, due to the time availability, only the computer results obtained by one-dimensional simulation are presented in this report. The one-dimensional EXPLORE code was used to obtain depth and velocity distributions in the study area. These were in turn fed to the time-dependent, two-dimensional sediment and pollutant transport code, FETRA to obtain longitudinal distributions of sediment and Kepone in the tidal James River. Hence, the results presented here are vertically and laterally averaged values changing with tidal flow.

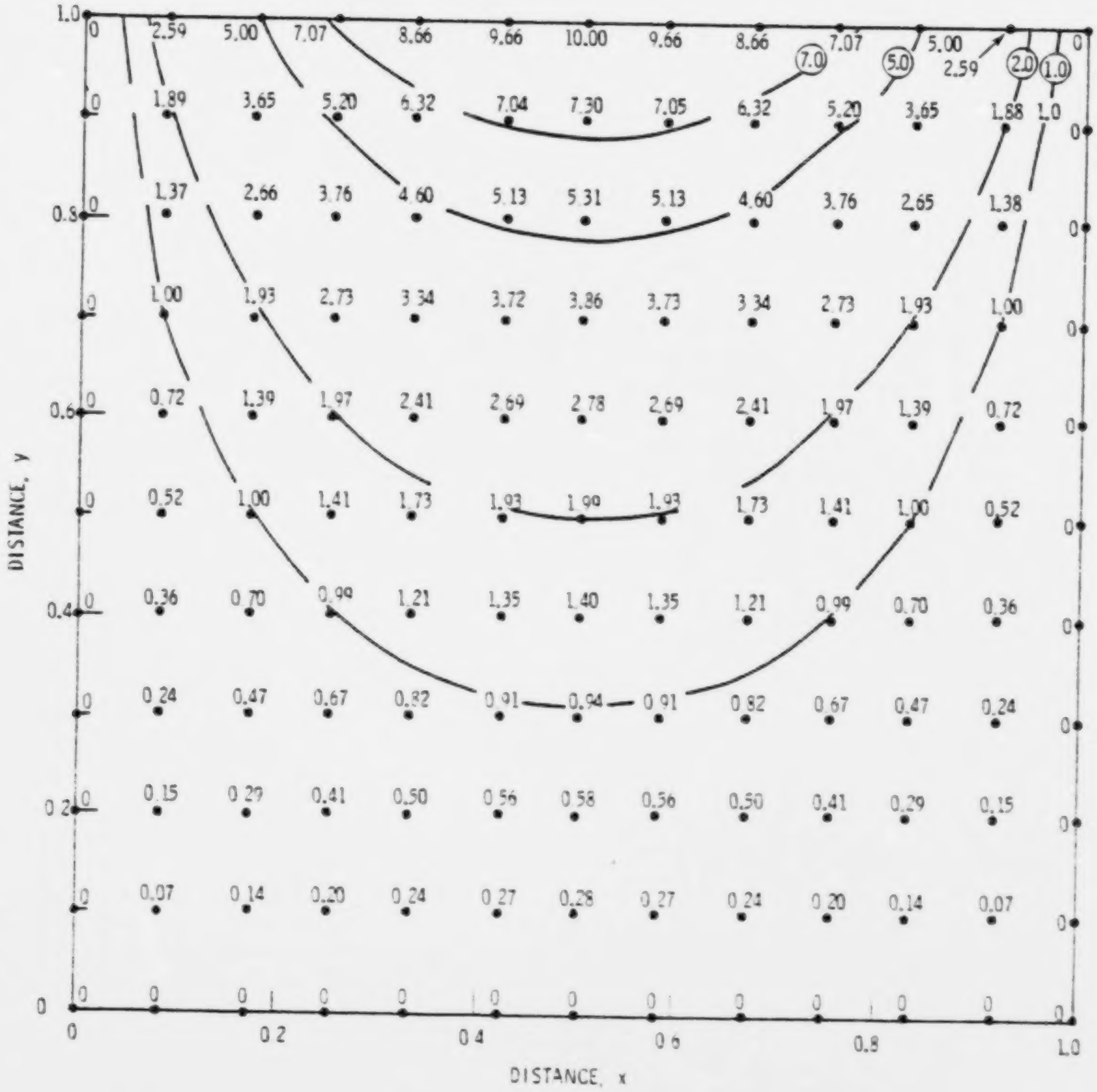


FIGURE M.4. Comparison of Numerical Solution with Analytical Solution to Two-Dimensional Diffusion Equation

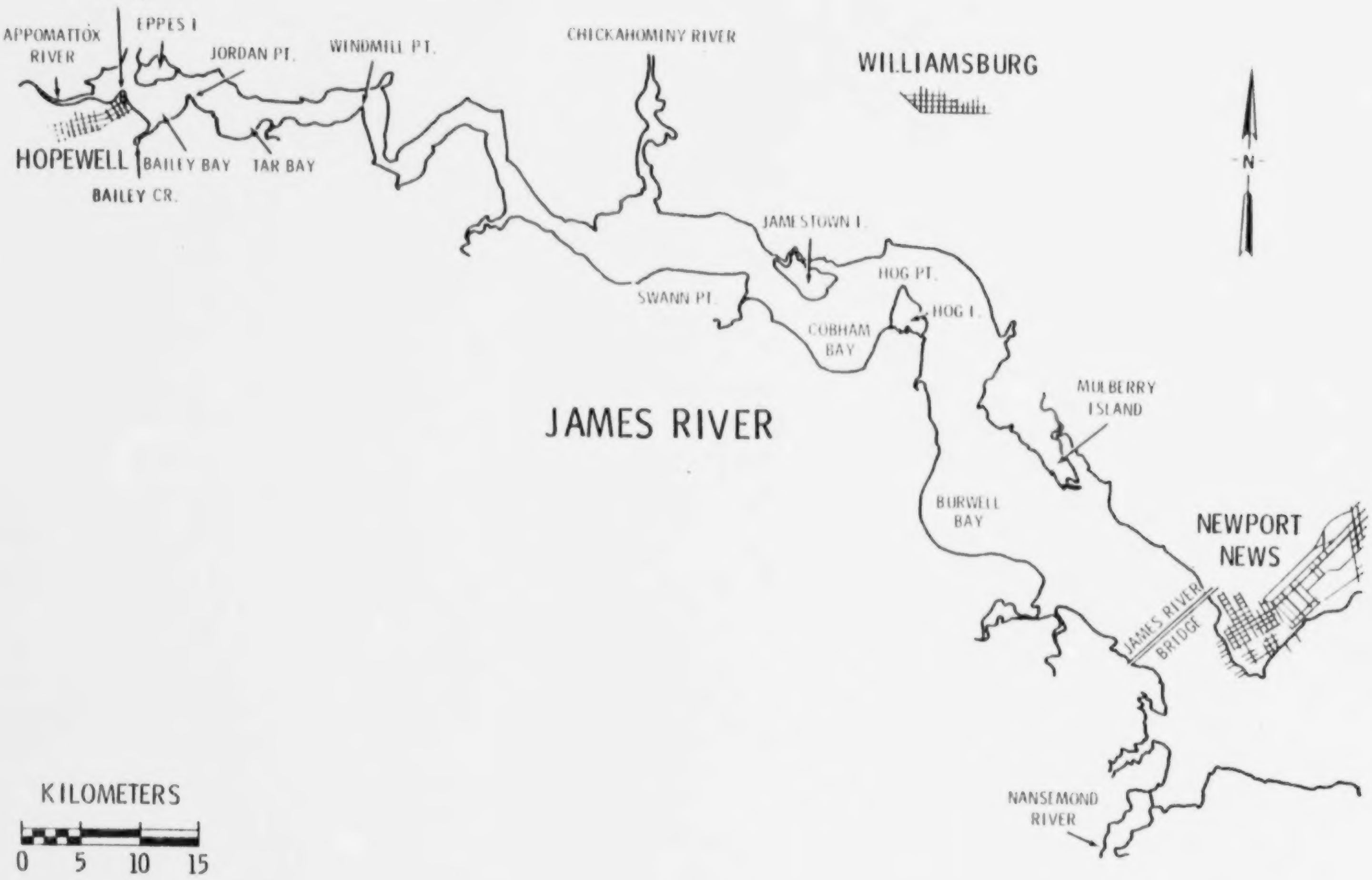

CITY PT.
APPOMATTOX RIVER
EPPES I
JORDAN PT.
WINDMILL PT.
HOPEWELL
BAILEY BAY
TAR BAY
BAILEY CR.
CHICKAHOMINY RIVER
WILLIAMSBURG
N
JAMESTOWN I.
HOG PT.
HOG I.
SWANN PT.
COBHAM BAY
JAMES RIVER
MULBERRY ISLAND
BURWELL BAY
NEWPORT NEWS
JAMES RIVER BRIDGE
NANSEMOND RIVER
KILOMETERS
0
5
10
15

FIGURE M.5. Tidal James River

The modeling procedure for the FETRA code involved simulating the transport of sediments (organic and inorganic materials) within the water body. The results were then input to models of dissolved and particulate Kepone in order to observe the interaction between sediment and Kepone. Finally, changes in river bed conditions were recorded, including: (1) river bottom elevation change, (2) ratio of cohesive sediment, noncohesive sediment and organic material, and (3) distribution of Kepone in the river bed.

Three flow discharge cases were simulated here: (1) a net fresh-water discharge of 58.3 m^3/sec (2,060 cfs) measured at City Point, (2) a net fresh-water discharge of 247 m^3/sec (8,700 cfs) measured at City Point, and (3) a net fresh-water discharge of 681 m^3/sec (24,000 cfs) measured at City Point. The net fresh-water discharge of 58.3 m^3/sec at City Point corresponds to that of approximately the 10 percentile discharge (Virginia Department of Conservation and Economic Development, 1970) (i.e., 10% of the time of the year the net fresh-water discharge is 58.3 m^3/sec or less). The second discharge of 247 m^3/sec corresponds to the average annual discharge, and the third discharge of 681 m^3/sec corresponds to approximately the 90 percentile discharge. Test conditions for these three cases are shown in Table M.1. The river sediments consist of cohesive sediment (silt and clay), organic matter and sand. Their particle sizes were assumed to be 0.030 mm, 0.100 mm and 0.150 mm, respectively. Distribution coefficients of Kepone associated with cohesive sediment, organic matter and sand were selected to be 10,000, 20,000 and 1,000 cm^3/g, respectively. Since the field data collected by Battelle in June 1977 are those for 58.3 m^3/sec, a major effort on the calibration and verification of the FETRA code was conducted for this discharge. After the model was calibrated, the other two discharge cases were tested without changing or readjusting the FETRA code except boundary conditions of sediment concentrations. In order to take into account the effect of the tide, the computer simulation was conducted for 31 days with a 30-min time step by simulating tidal motion. All sediment and Kepone computer results presented here were obtained on the 31st day of the simulation.

Case 1 - Net Fresh-water Discharge of 58.3 m^3/sec

Computer results of the longitudinal velocity and depth variations at maximum ebb, slack tide and maximum flood are shown in Figures M.6 through M.9, respectively. The velocity gradient with longitudinal distance is very evident.

Simulation of sediment and Kepone transport was conducted for each of the following substances: (1) cohesive sediment (clay and silt), (2) organic matter moving independent with cohesive sediment, (3) sand, (4) dissolved Kepone (5) particulate Kepone attached to cohesive sediment, (6) particulate Kepone associated with organic matter, and (7) particulate Kepone adsorbed by sand.

TABLE M.1. TEST CONDITIONS FOR KEPONE SIMULATION

	Case 1	Case 2	Case 3
Fresh-water Discharge (m^3/sec)	58.3	247	681
River Sediment Size (mm)			
Cohesive sediment	0.030	0.030	0.030
Organic matter	0.100	0.100	0.100
Sand	0.150	0.150	0.150
Longitudinal Dispersion Coefficients for all Sediment and Kepone (m^2/sec)	14	14	14
Longitudinal Diffusion Coefficients for all Sediment and Kepone (m^2/sec)	0.14	0.14	0.14
Kepone Decay Rate (1/hr)	0	0	0
Kepone Distribution Coefficients (cm^3/g)			
Associated with cohesive sediment	10,000	10,000	10,000
Associated with organic matter	20,000	20,000	20,000
Associated with sand	1,000	1,000	1,000
Kepone Mass Transfer Rate (1/hr)	1	1	1
Initial Bed Sediment Constituents (%)			
Cohesive sediment	80	80	80
Organic Matter	15	15	15
Sand	5	5	5
Boundary Conditions During Ebb Tide			
Sediment Concentrations at City Point (mg/ℓ)			
Cohesive sediment	24	32	52
Organic matter	4.5	6	9.8
Sand	1.5	2	3.2
Kepone Concentrations at City Point			
Dissolved (µg/ℓ)	0.007	0.007	0.007
Particulate (µg/g) associated with			
Cohesive sediment	0.045	0.045	0.045
Organic Matter	0.090	0.090	0.090
Sand	0.0045	0.0045	0.0045
Boundary Conditions During Flood Tide			
Sediment Concentrations at Burwell Bay (mg/ℓ)			
Cohesive sediment	24	32	52
Organic matter	4.5	6	9.8
Sand	1.5	2	
Kepone Concentrations at Burwell Bay			
Dissolved (µg/ℓ)	0.007	0.007	0.007
Particulate (µg/g) associated with			
Cohesive sediment	0.032	0.032	0.032
Organic matter	0.064	0.064	0.064
Sand	0.0032	0.0032	0.0032

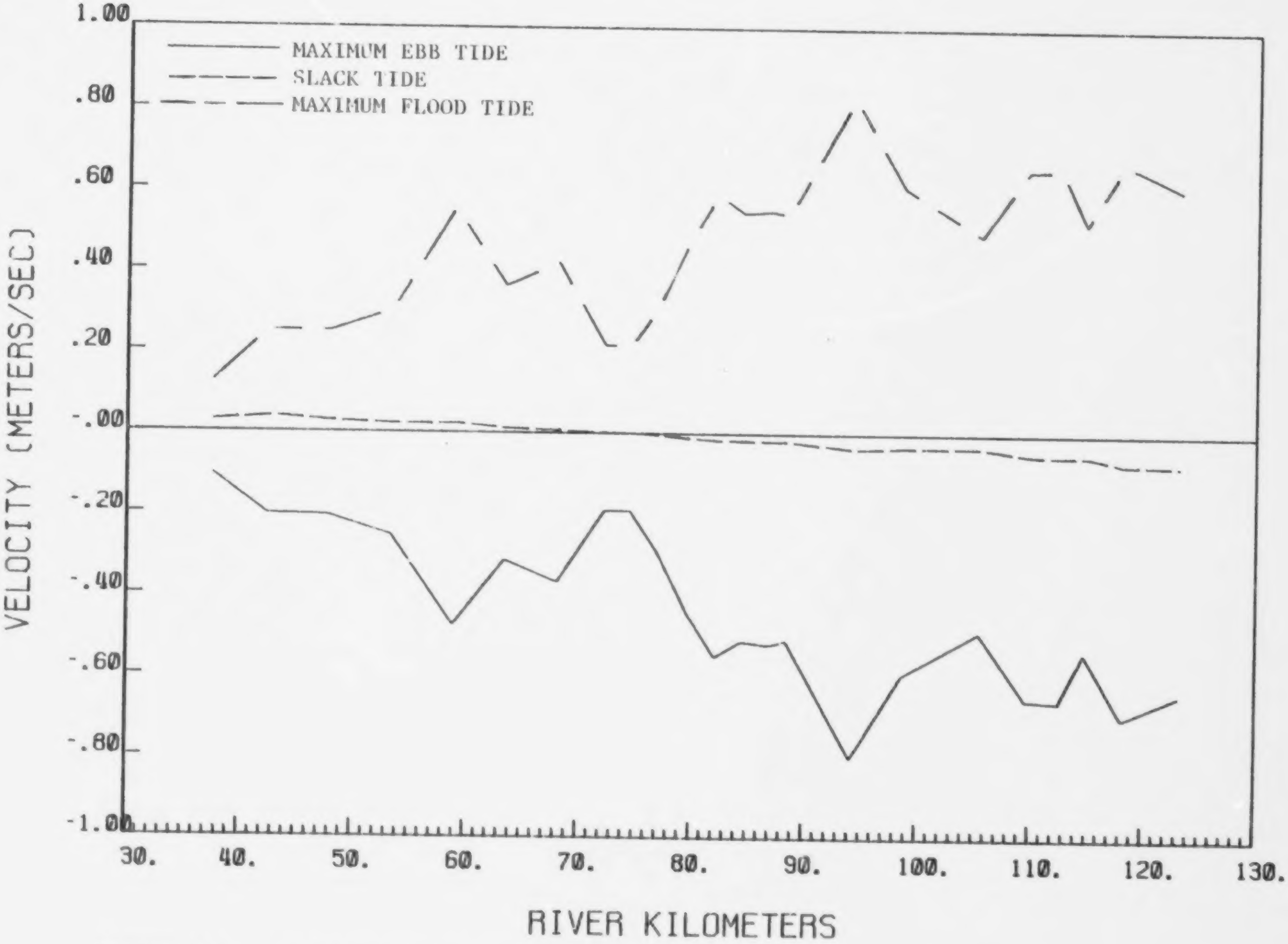


FIGURE M.6. Longitudinal Velocity Distributions at Maximum Ebb, Slack and the Maximum Flood Tides for Fresh-water Input Discharge of 58.3 m^3/sec

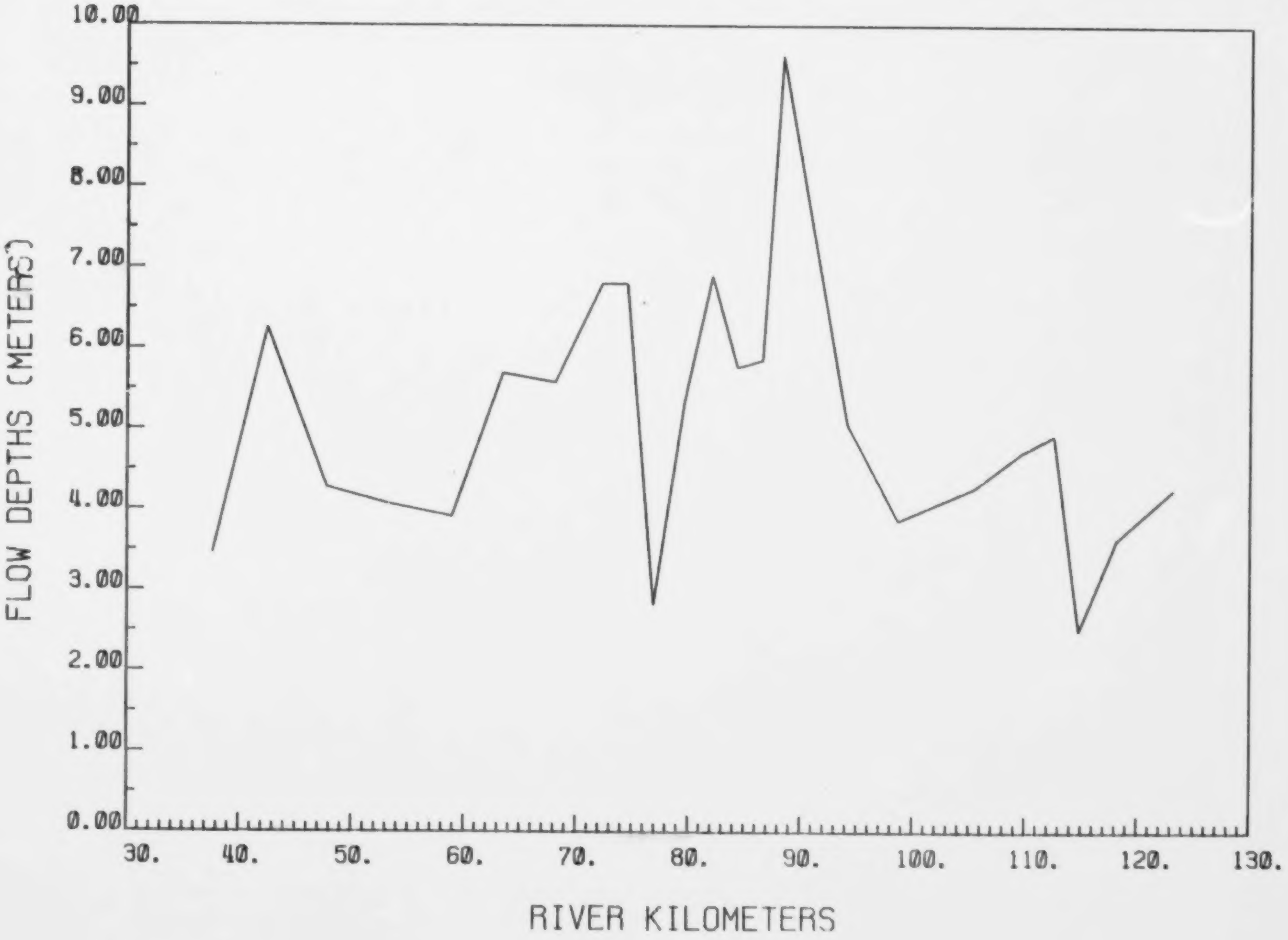


FIGURE M.7. Longitudinal Depth Variation at Maximum Ebb Tide for the Fresh-water Discharge of 58.3 m^3/sec

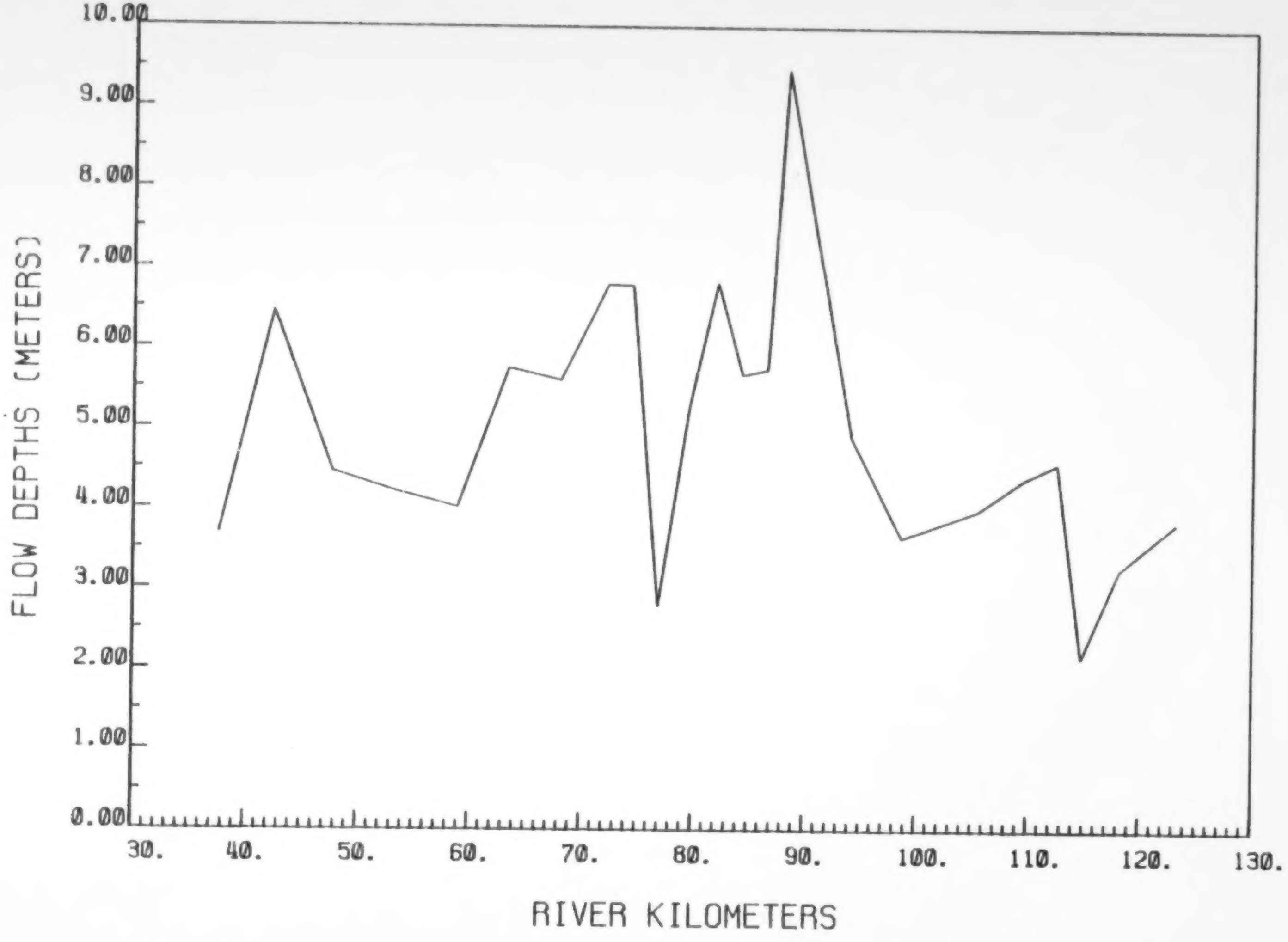
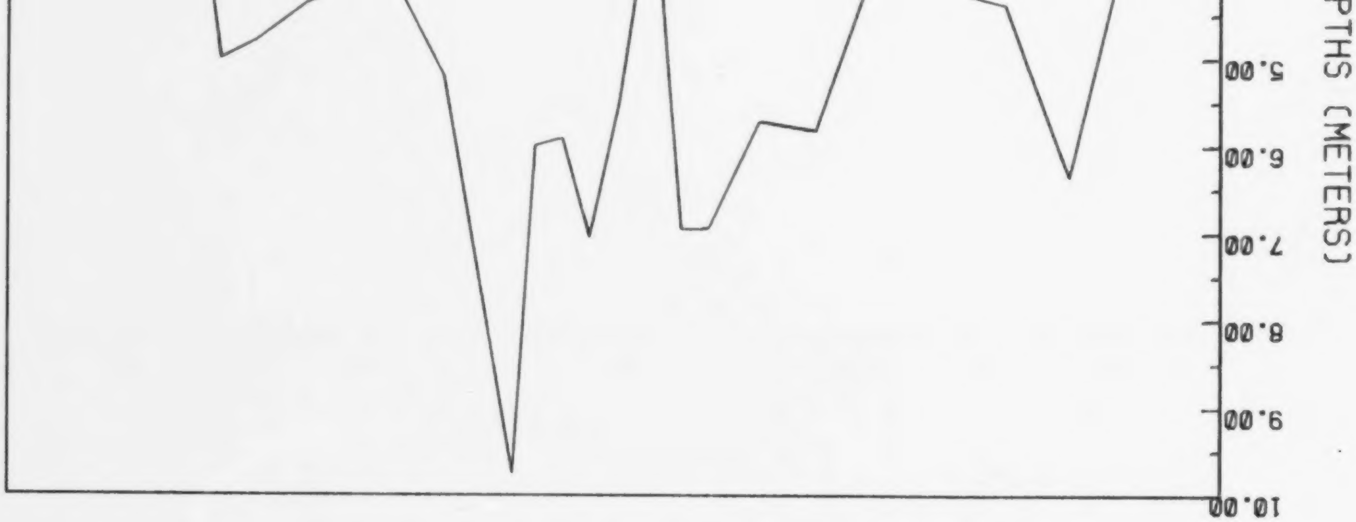


FIGURE M.8. Longitudinal Depth Variation at Slack Tide for the Fresh-water Discharge of 58.3 m^3/sec


5.00
6.00
7.00
8.00
9.00
10.00
PTHS (METERS)

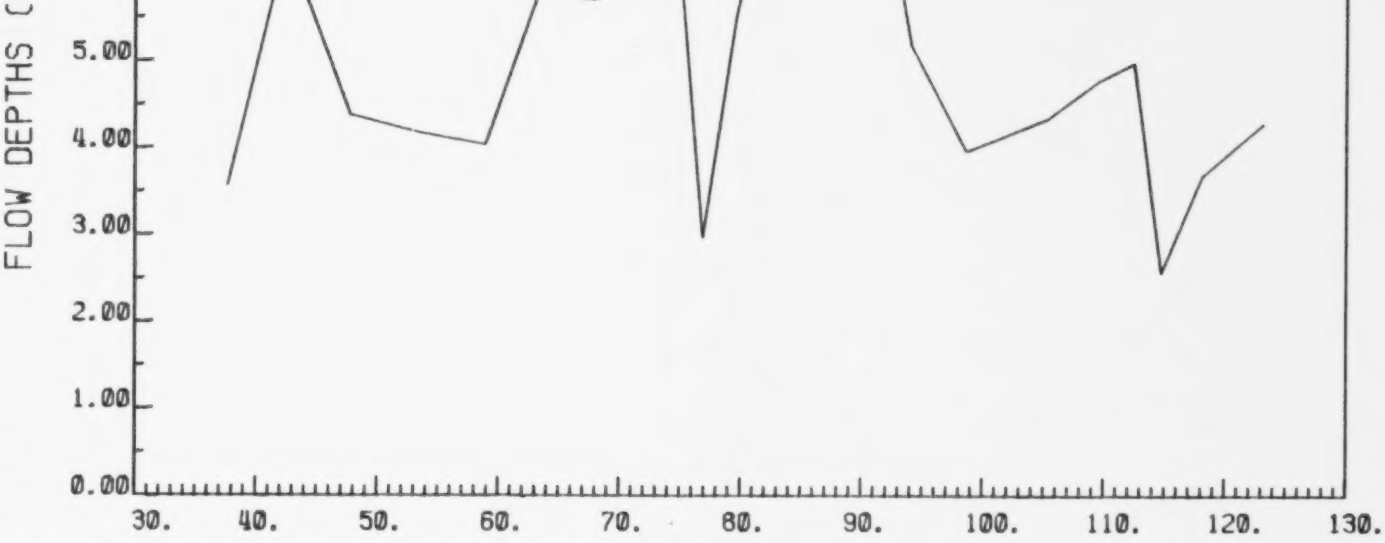


FIGURE M.9. Longitudinal Depth Variations at Maximum Flood Tide for the Fresh-water Discharge of 58.3 m^3/sec

Figures M.10 through M.12 show computed longitudinal variations of total sediment concentration (sum of cohesive sediment, organic matter and sand being transported as suspended and bed loads) at maximum ebb, slack tide and maximum flood, respectively. Comparison of the computer results with the measured data indicate excellent agreement as discussed in Chapter VII. Field data shown in this figure are cross-sectionally averaged values obtained by the measured data. Sediment concentrations vary from approximately 80 mg/ℓ to 10 mg/ℓ in the study area. Average total sediment concentrations in this area at maximum ebb, slack and maximum flood tides are predicted to be 36, 29 and 42 mg/ℓ, respectively. Figures M.13 through M.15 show longitudinal distributions of each sediment component, i.e., cohesive sediment, organic matter, sand and total sediment for maximum ebb, slack and maximum flood tides, respectively. These figures indicate that 70 to 90% of the suspended sediment is silt and clay. The organic matter comprises 10 to 30%. The suspended sand has an insignificant concentration. These values are comparable to measured values obtained by Battelle under this study and by Nichols (1972). Changes of sediment concentrations with time at River Kilometer 75.7 are shown in Figure M.16. The maximum ebb occurs at approximately 3 and 15 hr while the maximum flood occurs at approximately 8 and 21 hr. Sediment concentrations oscillate with time due to tidal motion, producing peaks at maximum ebb and flood (with a maximum of 70 mg/ℓ) and minimum values (with the lowest concentration of 23 mg/ℓ) at near slack tide. This figure indicates that approximately 64 to 33% of the sediment remains suspended during slack tide. Note that after 25 hr, the sediment concentration level returns to its starting value indicating this periodic pattern reaches its equilibrium condition. Figure M.17 shows longitudinal distributions of tidal averaged sediment concentrations for each sediment component and the total sediment. The total sediment concentration in this 86-km reach varies from approximately 50 mg/ℓ to 20 mg/ℓ with the average value of 33.2 mg/ℓ. Tidal averaged sediment concentrations of cohesive sediment, organic material and sand averaged over the study area are 28.9, 4.1 and 0.2 mg/ℓ, respectively. These constitute approximately 87.0, 12.4 and 0.6% of the total sediment constituents, respectively. The longitudinal variation of sediment concentration is relatively small due to the lack of a clear null zone (area where fresh and saline water intermix), (see Figures VII.16 through VII.18), because of the very low net fresh-water input for this case. The small but still measurable longitudinal variation may be attributed to the change in the tidal James River topography ranging from wide bays to narrow channels connecting bays.

Figures M.18 through M.20 present predicted particulate Kepone concentrations associated with each type of sediment and average particulate Kepone (weighted average of three particulate Kepone values associated with the three sediment types) per unit weight of sediment, together with cross-sectionally averaged field data, for maximum ebb, slack and maximum flood tides, respectively. Comparison of computer results of total particulate Kepone and the measured data reveals good agreement as discussed in Chapter VII.

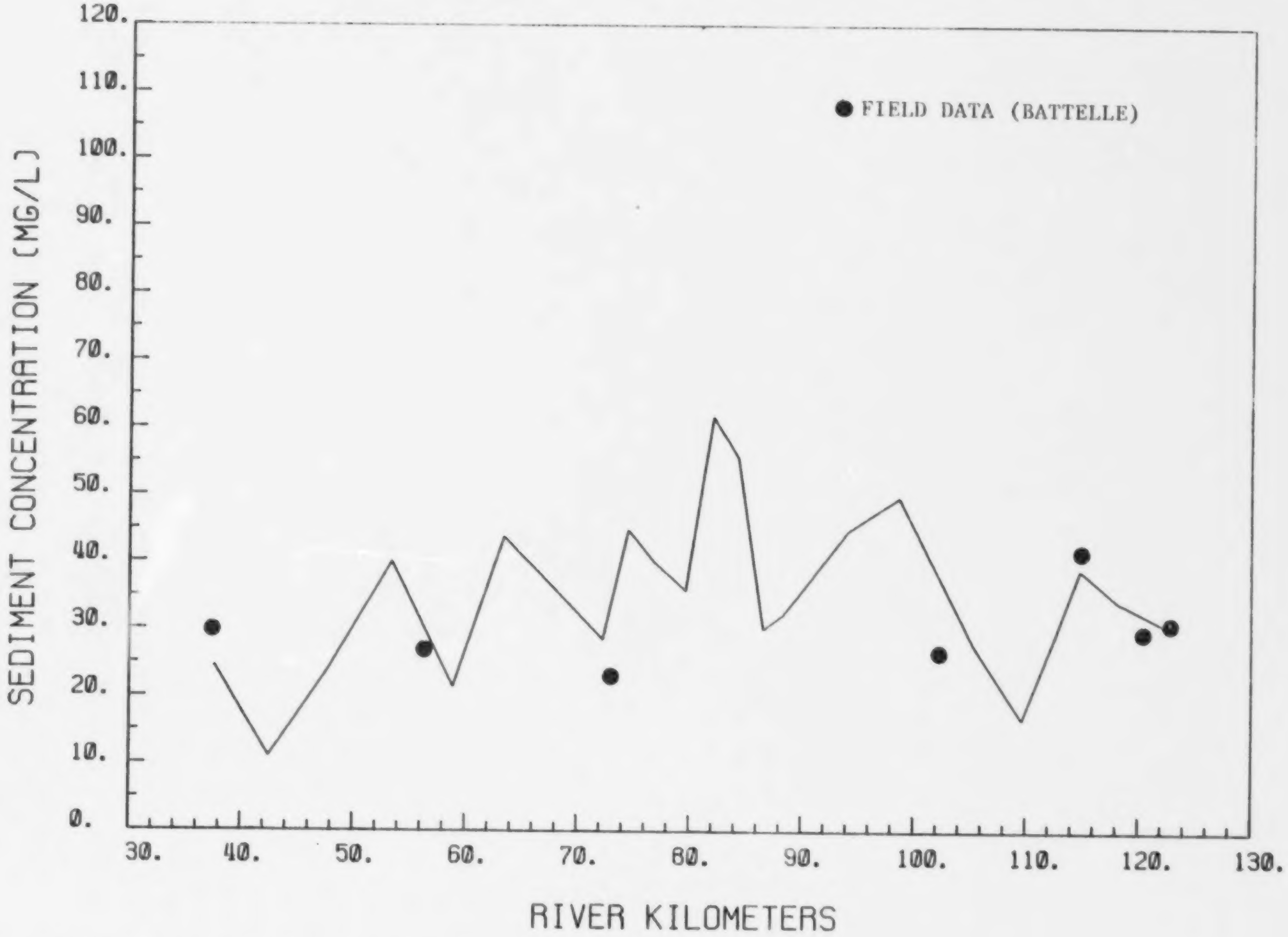


FIGURE M.10. Longitudinal Distributions of Total Sediment Concentration at the Maximum Ebb Tide for the Fresh-water Discharge of 58.3 m^3/sec, together with Field Data

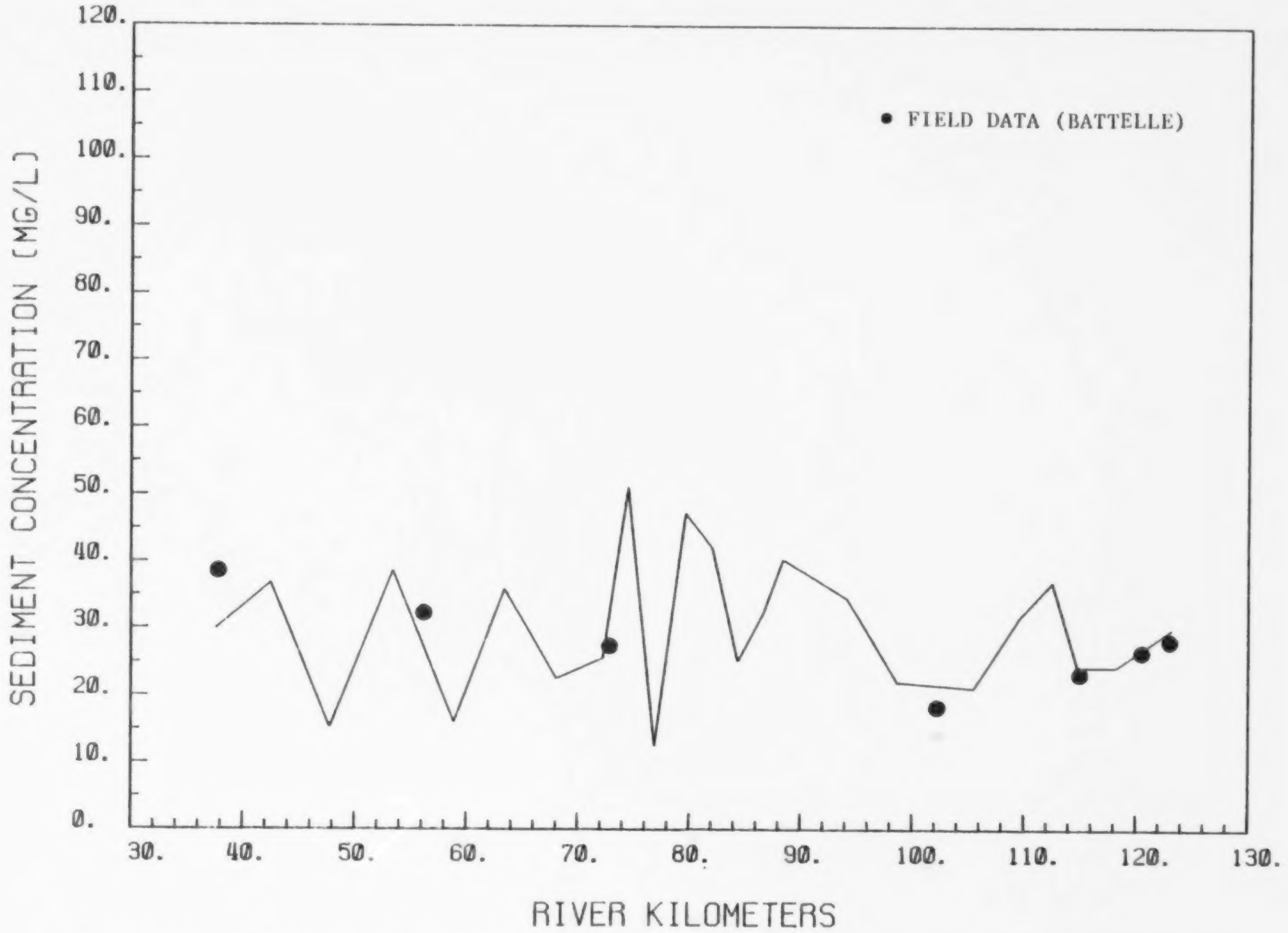


FIGURE M.11. Longitudinal Distributions of Total Sediment Concentration at the Slack Tide for the Fresh-water Discharge of 58.3 m^3/sec, together with Field Data

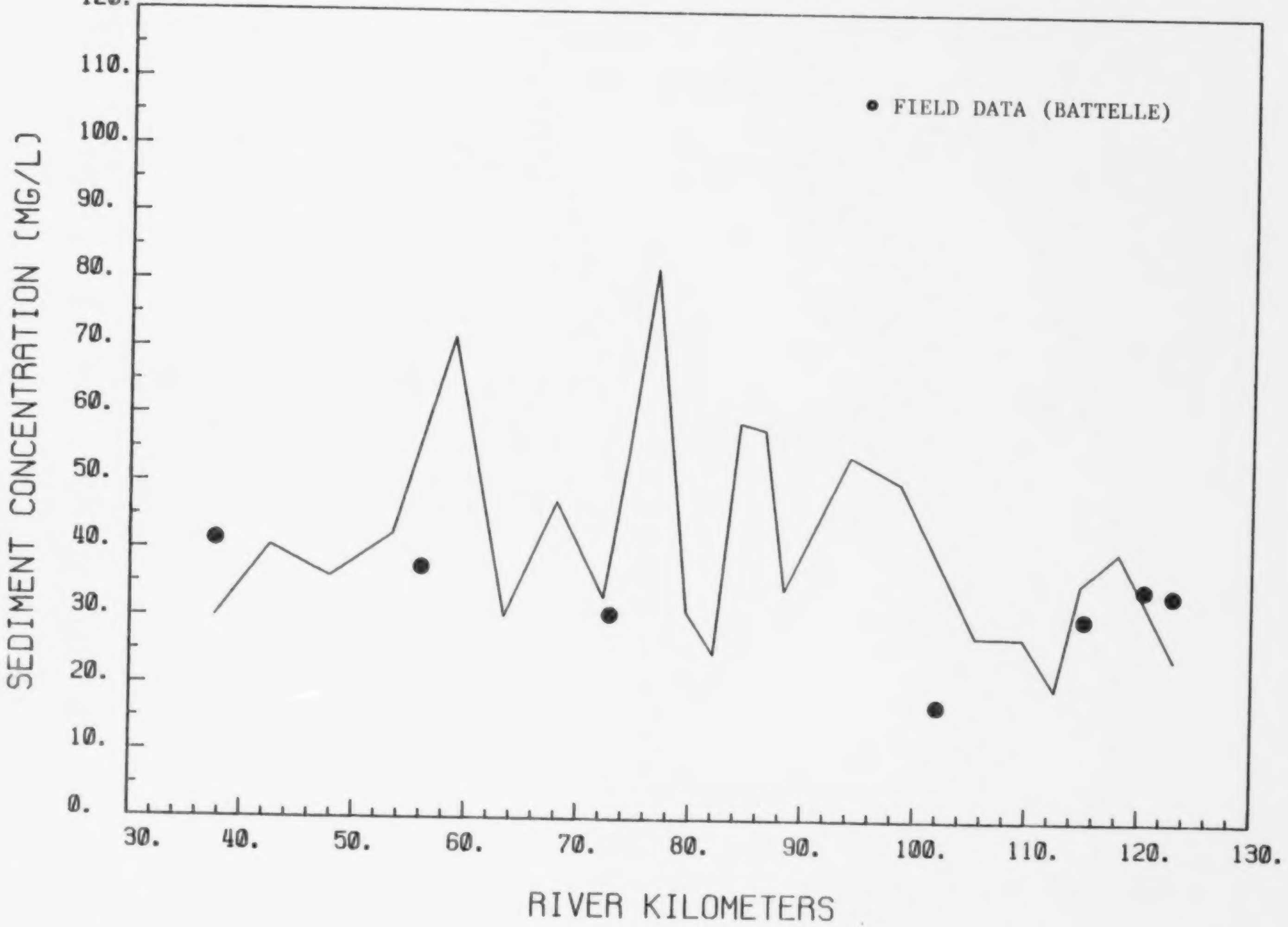


FIGURE M.12. Longitudinal Distributions of Total Sediment Concentration at the Maximum Flood Tide for the Fresh-water Discharge of 58.3 m^3/sec, together with Field Data

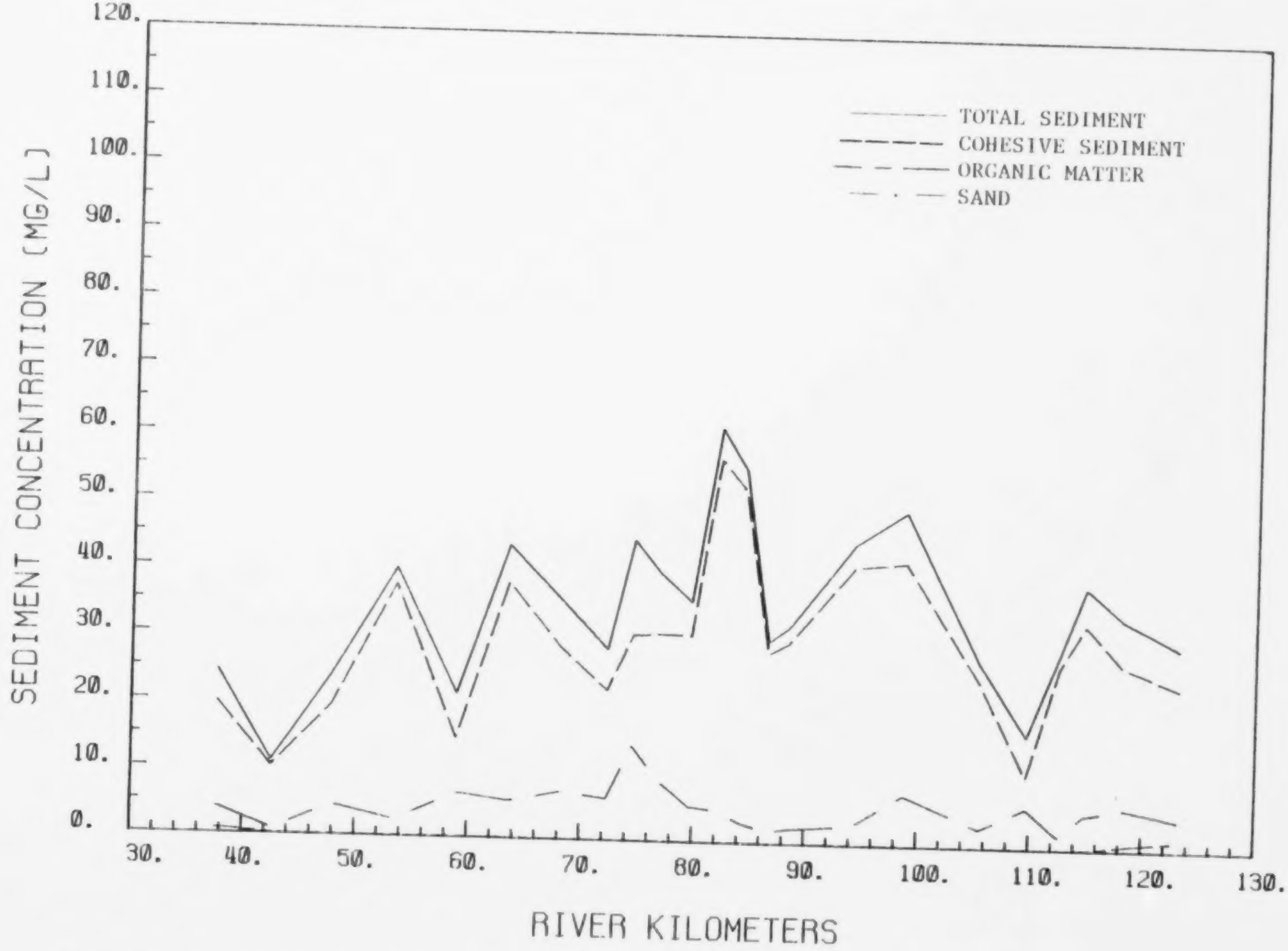


FIGURE M.13. Longitudinal Distribution of Sediment Concentration of Each Sediment Type at Maximum Ebb Tide for the Fresh-water Discharge of 58.3 m^3/sec

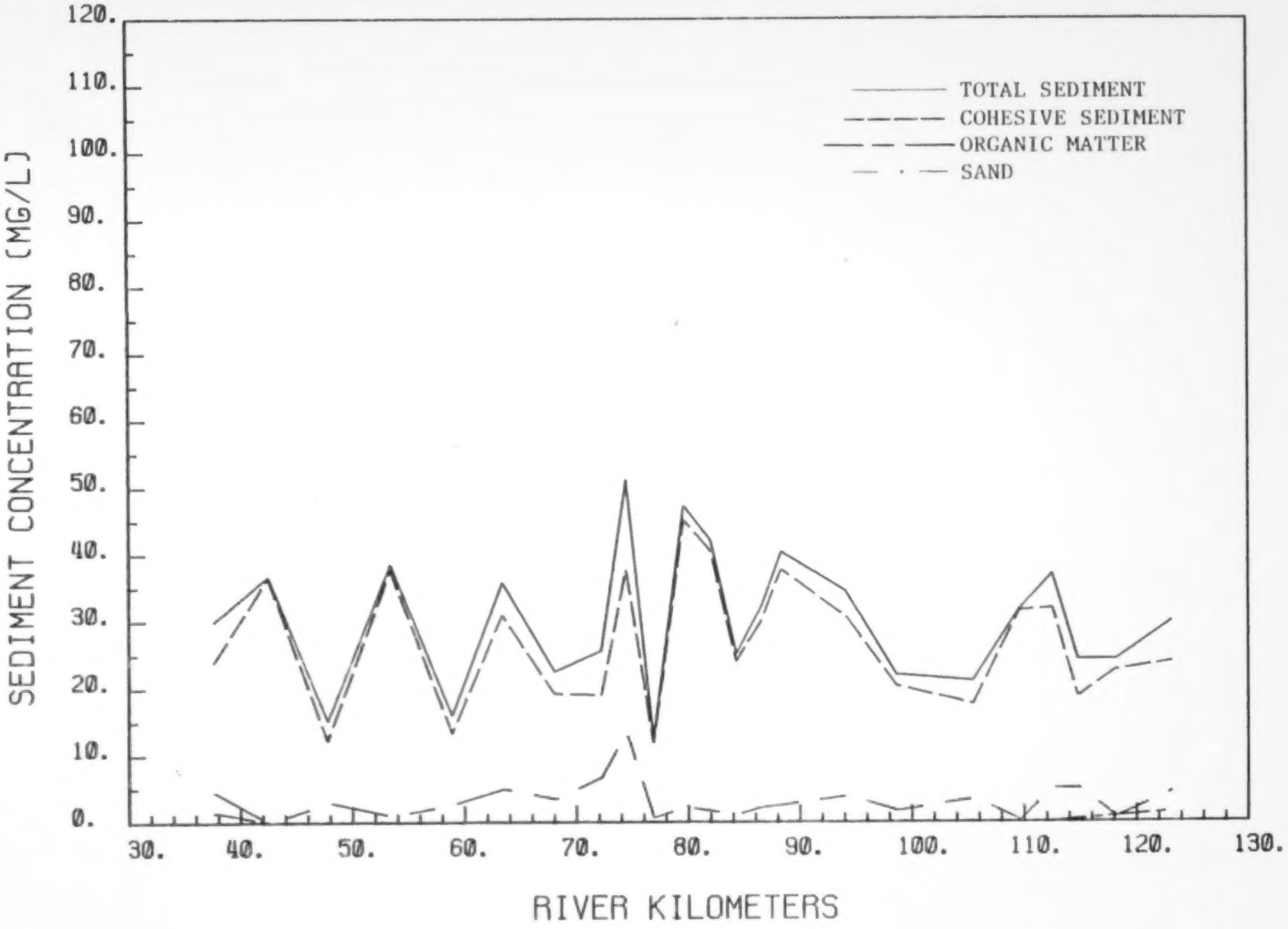


FIGURE M.14. Longitudinal Distribution of Sediment Concentration of Each Sediment Type at Slack Tide for the Fresh-water Discharge of 58.3 m^3/sec

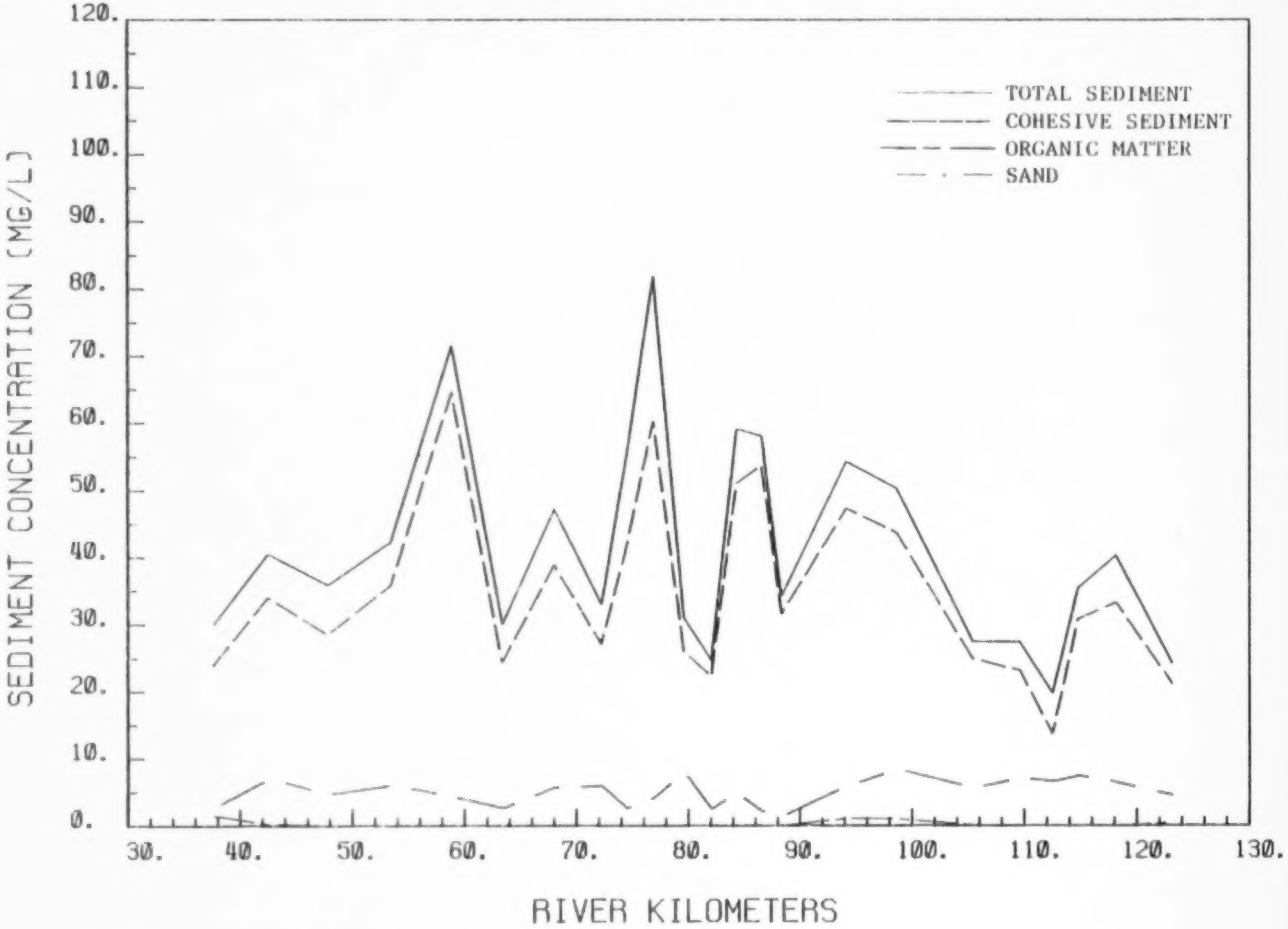


FIGURE M.15. Longitudinal Distributions of Sediment Concentration of Each Sediment Type at Maximum Flood Tide for the Fresh-water Discharge of 58.3 m^3/sec

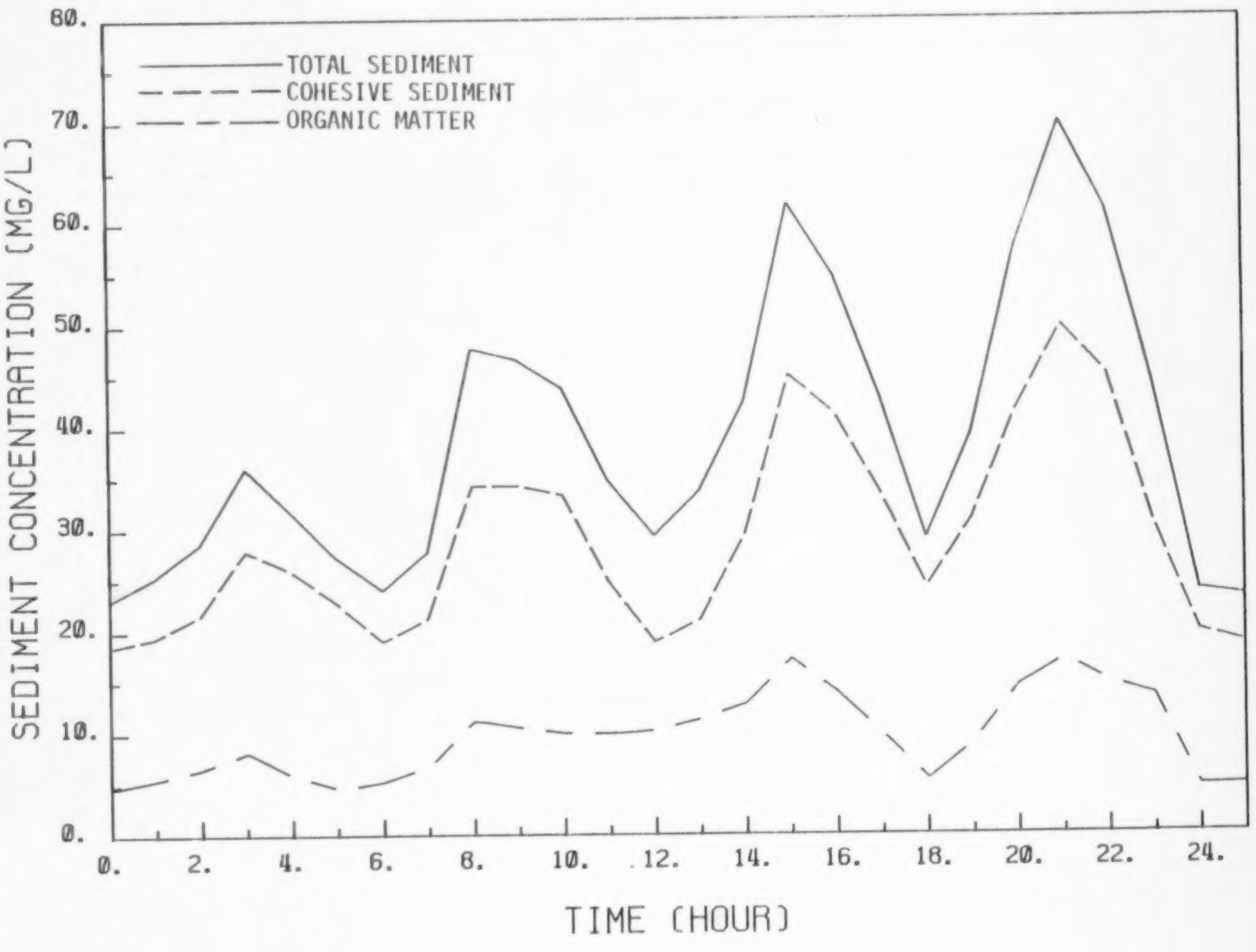


FIGURE M.16. Changes of Sediment Concentrations with Time at River Kilometer 75.7 for the Fresh-water Discharge of 58.3 m^3/sec

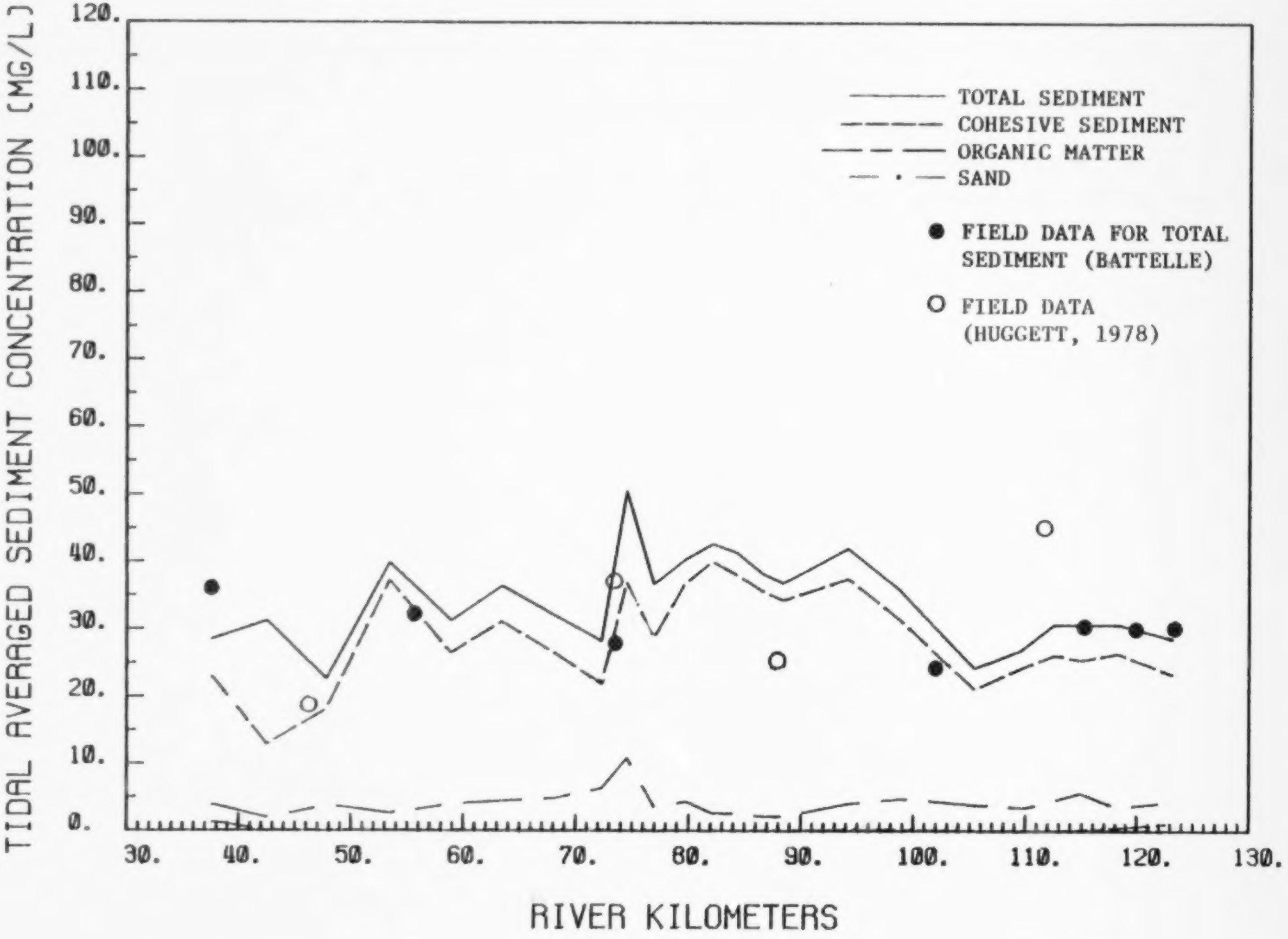


FIGURE M.17. Tidal Averaged Sediment Concentration of Each Sediment Type for the Fresh-water Discharge of 58.3 m^3/sec

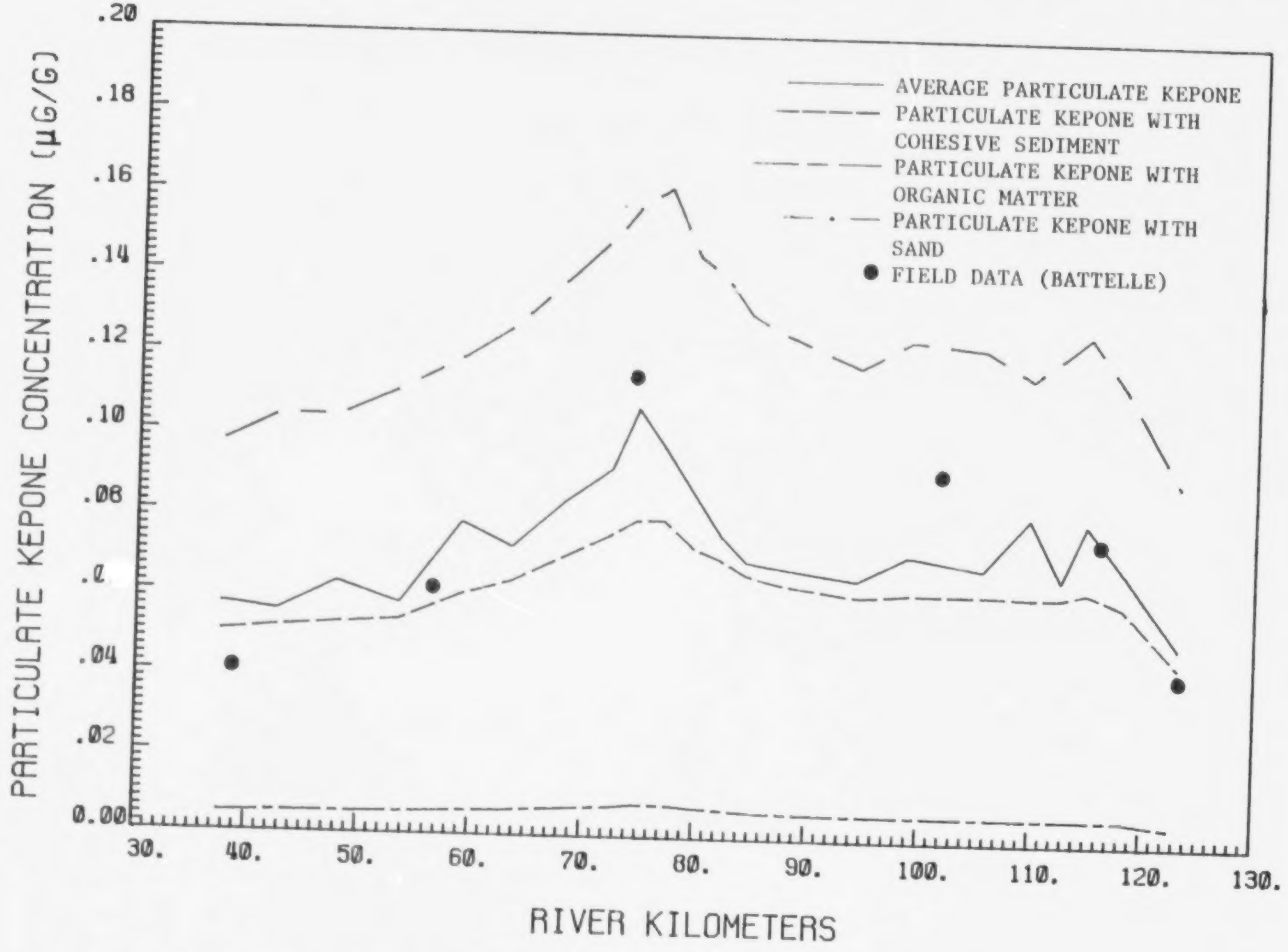


FIGURE M.18. Longitudinal Distributions of Particulate Kepone Concentrations at Maximum Ebb Tide for the Fresh-water Discharge to 58.3 m^3/sec

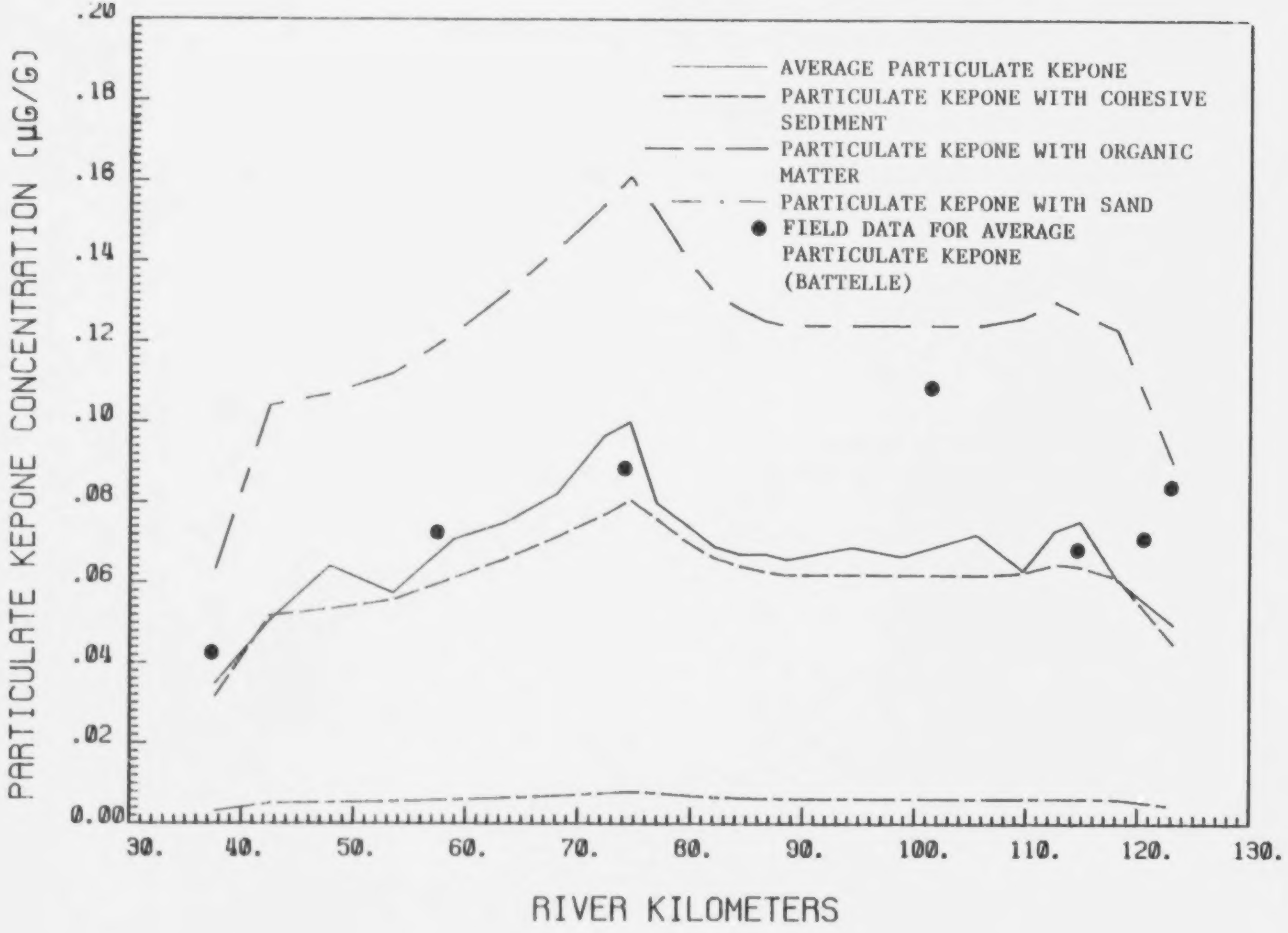


FIGURE M.19. Longitudinal Distributions of Particulate Kepone Concentrations at Slack Tide for the Fresh-water Discharge 58.3 m^3/sec

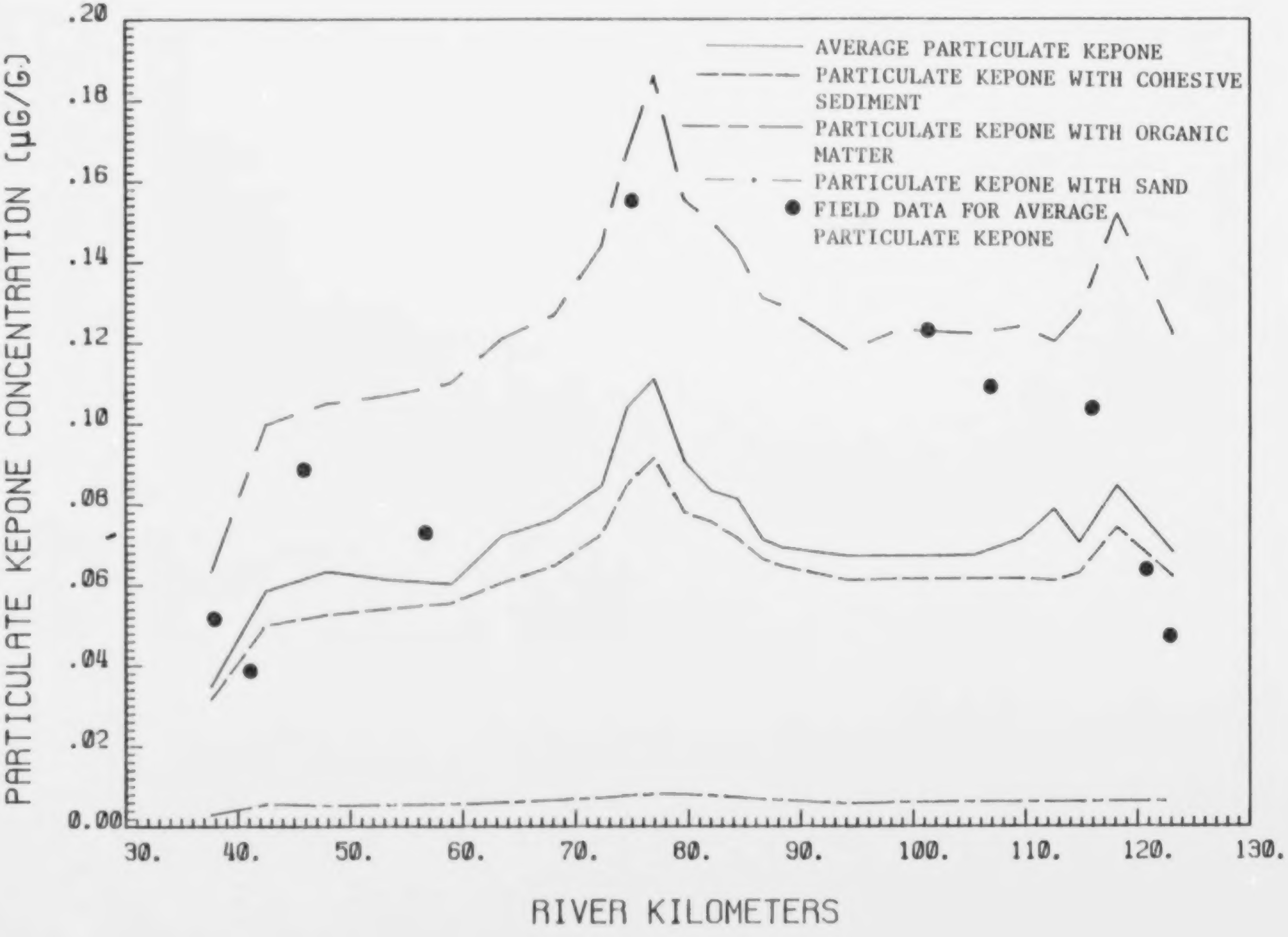


FIGURE M.20. Longitudinal Distributions of Particulate Kepone Concentrations of Maximum Flood Tide for the Fresh-water Discharge of 58.3 m^3/sec

The mathematical simulation results indicate that the particulate Kepone concentration generally increases from 0.05 μg/g to 0.11 μg/g with movement seaward from City Point (River Kilometer 123) to the confluence of the James River and the Chickahominy River (River Kilometer 77) with an intermediate peak around Bailey Bay and Jordan Point (River Kilometer 118). Seaward from the James-Chickahominy River confluence, the particulate Kepone concentration decreases gradually and has a value of approximately 0.04 μg/g in Burwell Bay (River Kilometer 37.6). These figures also reveal that the Kepone concentration associated with the organic material is approximately twice as high as those attached to the cohesive sediment which in turn have 10 times higher Kepone concentration than those adsorbed by sand. Changes of particulate Kepone concentrations with time at River Kilometer 75.7 are shown in Figure M.21. There are small peaks associated with maximum ebb and flood tides due to possible erosion of bed sediment with high Kepone concentrations. Tidal averaged particulate Kepone concentrations, together with the tidal averaged field data are shown in Figure M.22. Good agreement was obtained between the computer results and the measured value. It is shown in this figure that the total particulate Kepone concentration averaged over the 86-km reach is 0.071 μg/g. This figure also shows that as area wide averages, particulate Kepone adsorbed by the cohesive sediment, organic matter and sand are 0.063, 0.126, and 0.006 μg/g, respectively.

Figures M.23 through M.25 also present particulate Kepone concentration, only on a per unit volume of water basis for the three tidal stages, respectively. These values were obtained by multiplying particulate Kepone concentration per unit weight of sediment times the sediment concentration. Figure M.26 shows the tidal averaged particulate Kepone concentration in μg/ℓ. Although the organic matter contains the highest Kepone concentration (see Figure M.22), this figure reveals that the suspended cohesive sediments (silt and clay) carries the greatest amount of Kepone among particulate Kepone because of its high sediment concentration in the water. For example, as shown in Figure M.26, in the vicinity of the confluence of the James and Chickahominy Rivers (River Kilometer 77), total particulate Kepone concentration is 0.0037 μg/ℓ, of which 66% is transported in a particulate form associated with the cohesive sediment. While approximately 34% of the particulate Kepone associates with the organic material. No measurable Kepone was associated with suspended sand.

Longitudinal variations of dissolved, particulate and total (sum of dissolved and total particulate Kepone) Kepone concentrations are presented in Figures M.27 through M.31. These figures reveal that total Kepone concentrations vary from approximately 0.006 μg/ℓ to 0.0132 μg/ℓ with the peak concentration occurring at River Kilometer 75 (in the vicinity of the Swann Point). Concentrations of dissolved, particulate and total Kepone averaged over the 86-km reach are 0.0065, 0.0024, and 0.089 μg/ℓ. These values indicate that approximately 27% of total Kepone is carried by sediment, while 73% remains in the dissolved form, as overall average values. These figures also show that suspended sediment carries approximately 10 to 50% of the total Kepone, while 50 to 90% of the Kepone is transported in a dissolved form for this discharge case. For example, at River Kilometer 77, 32% of Kepone is transported in a particulate form, while 68% is in a dissolved form at maximum ebb tide.

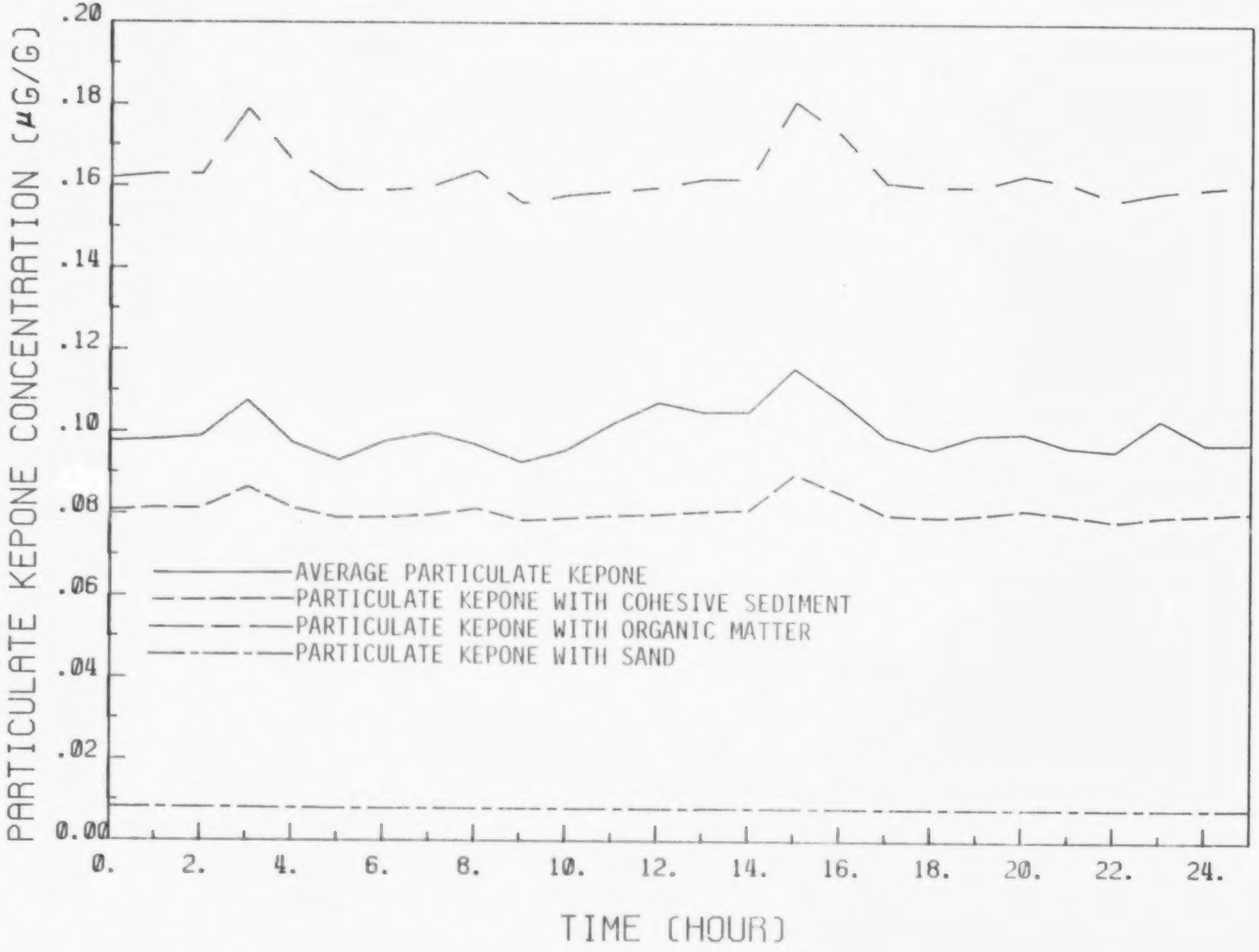


FIGURE M.21. Changes of Particulate Kepone Concentrations with Time at River Kilometer 75.7 for the Fresh-water Discharge of 58.3 m^3/sec

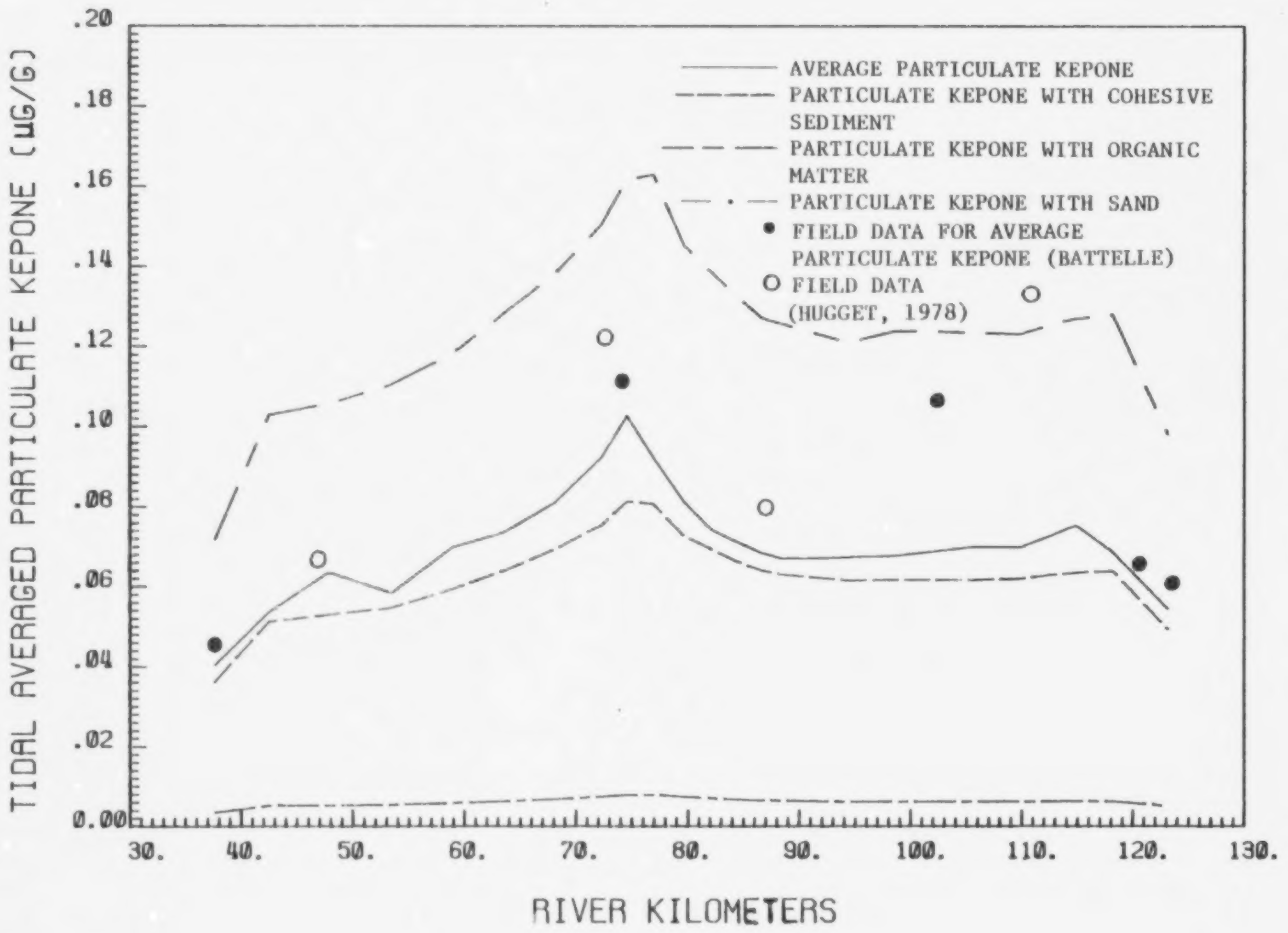


FIGURE M.22. Tidal Averaged Particulate Kepone Concentrations for the Fresh-water Discharge of 58.3 m^3/sec

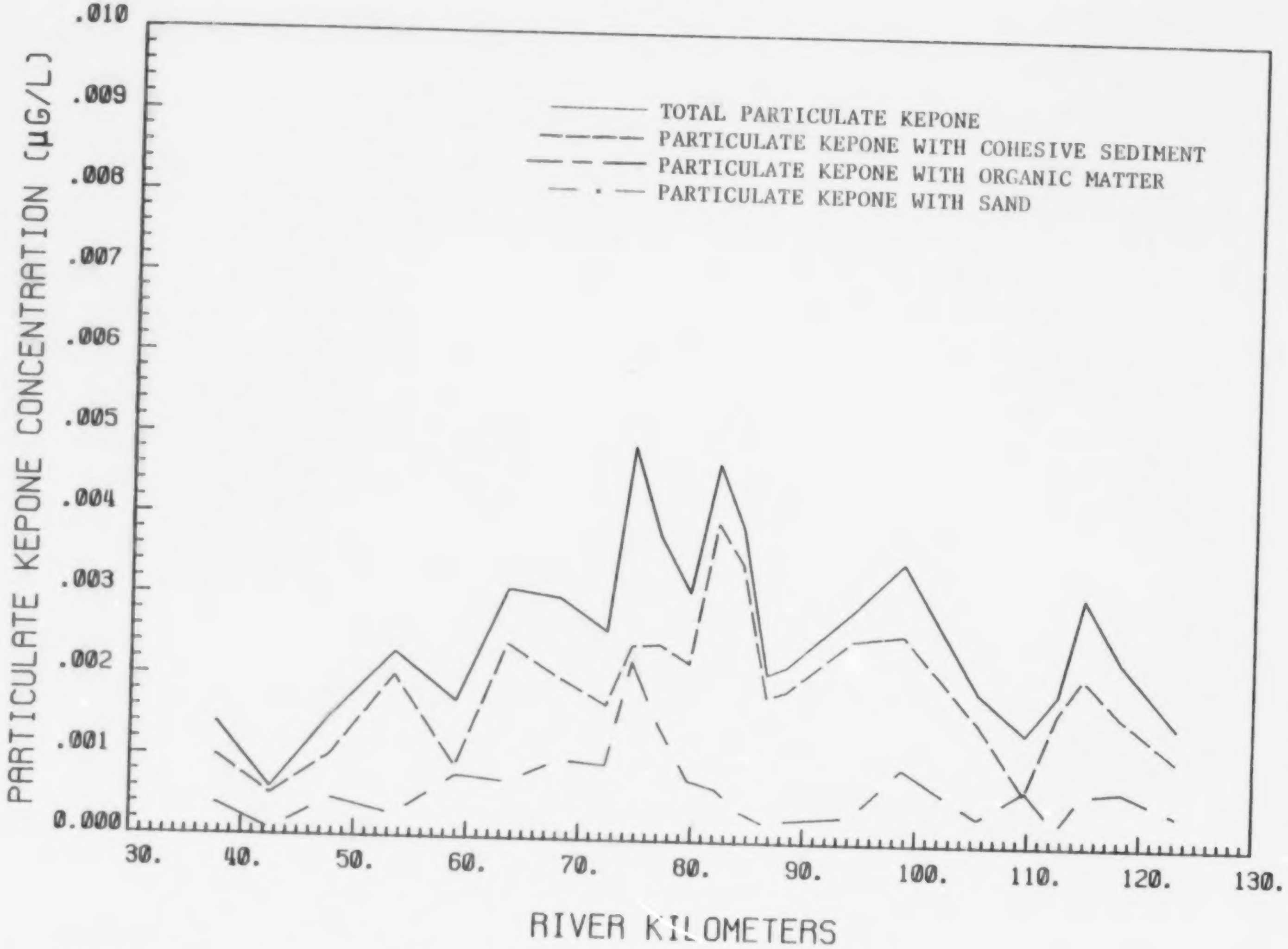


FIGURE M.23. Longitudinal Distributions of Particulate Kepone Concntrations per Unit Volume of Water at Maximum Ebb Tide for the Fresh-water Discharge of 58.3 m^3/sec

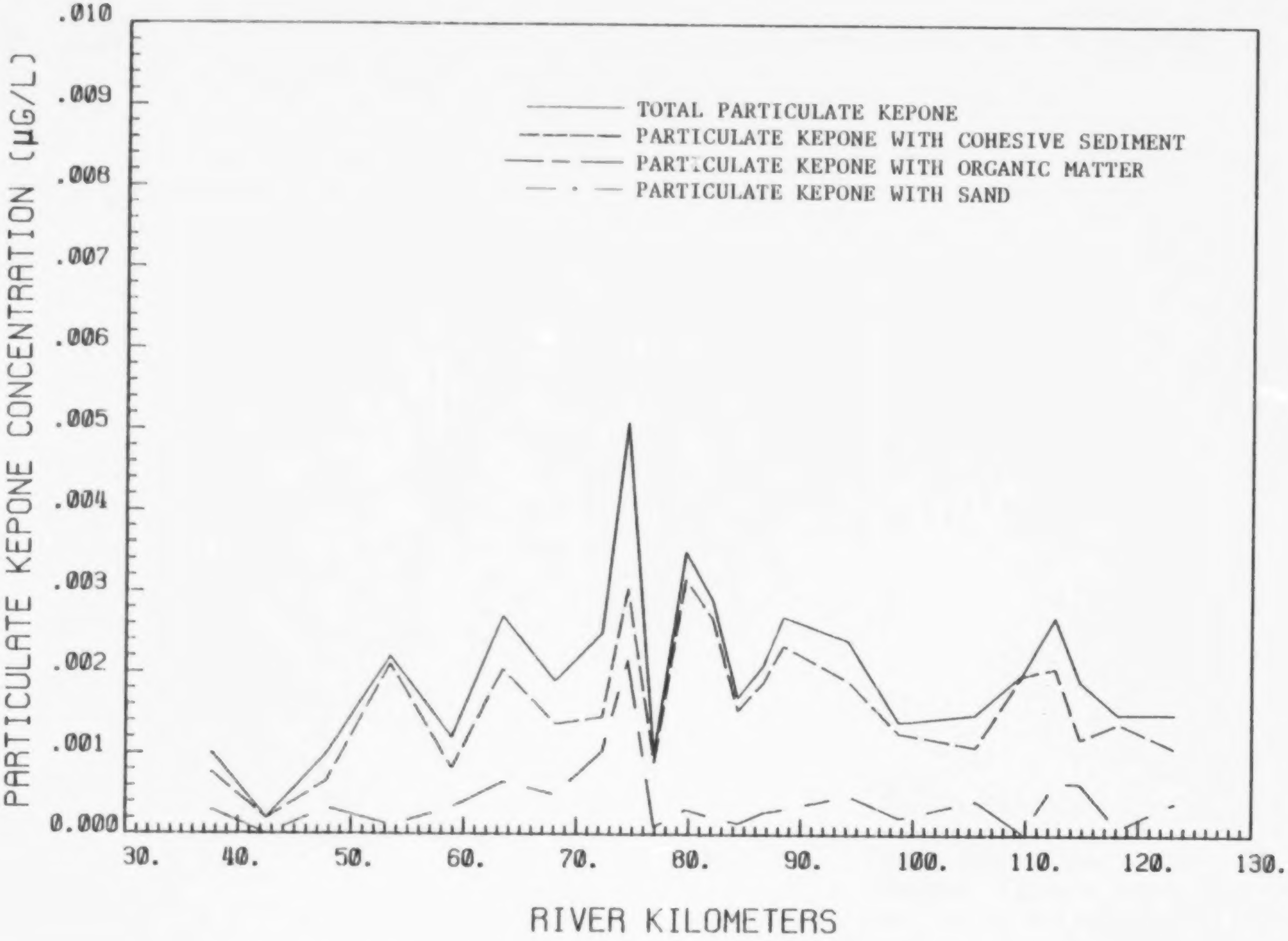


FIGURE M.24. Longitudinal Distributions of Particulate Kepone Concentrations per Unit Volume of Water at Slack Tide for the Fresh-water Discharge of 58.3 m^3/sec

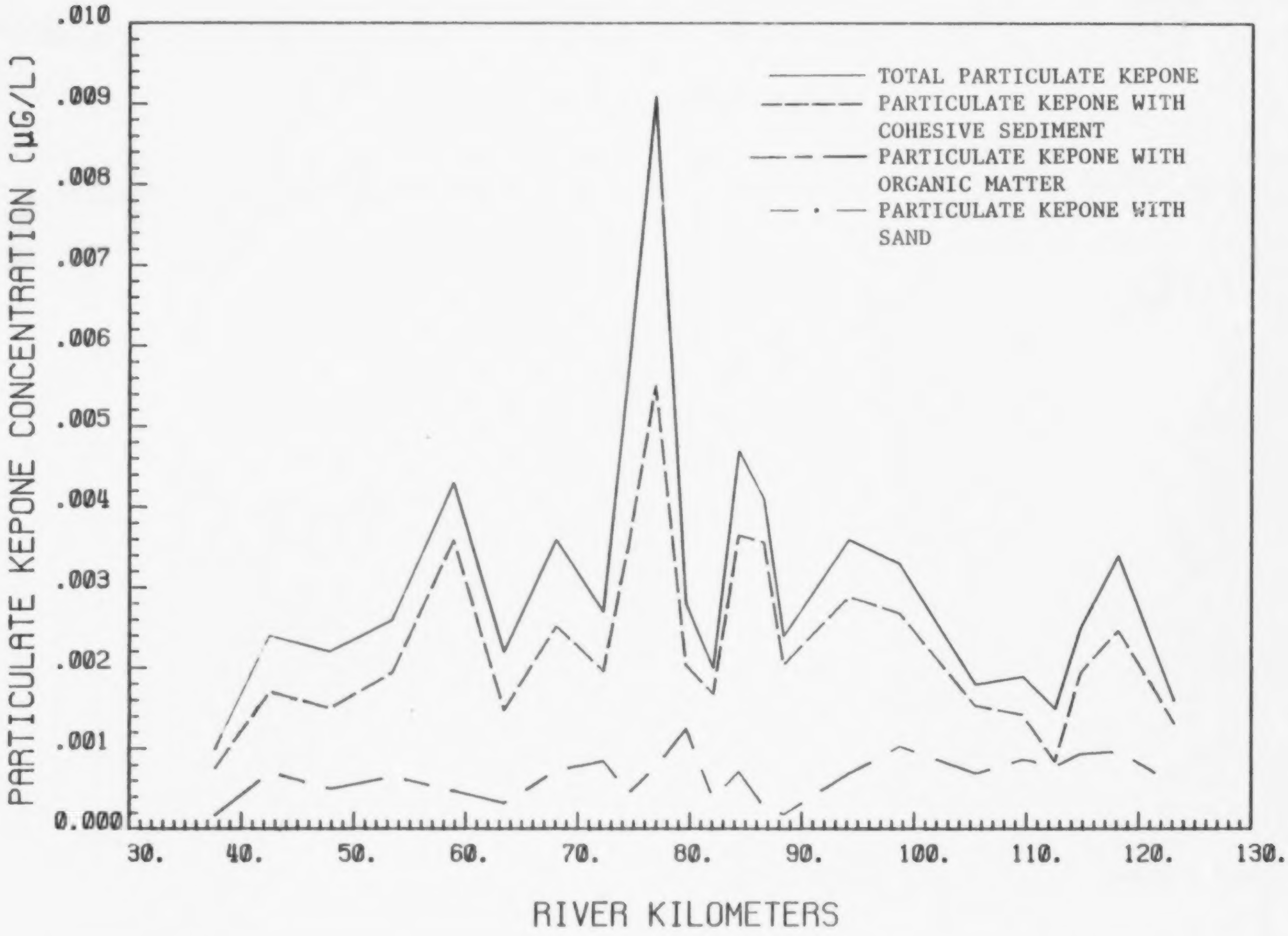


FIGURE M.25. Longitudinal Distributions of Particulate Kepone Concentrations per Unit Volume of Water at Maximum Flood Tide for the Fresh-water Discharge of 58.3 m^3/sec

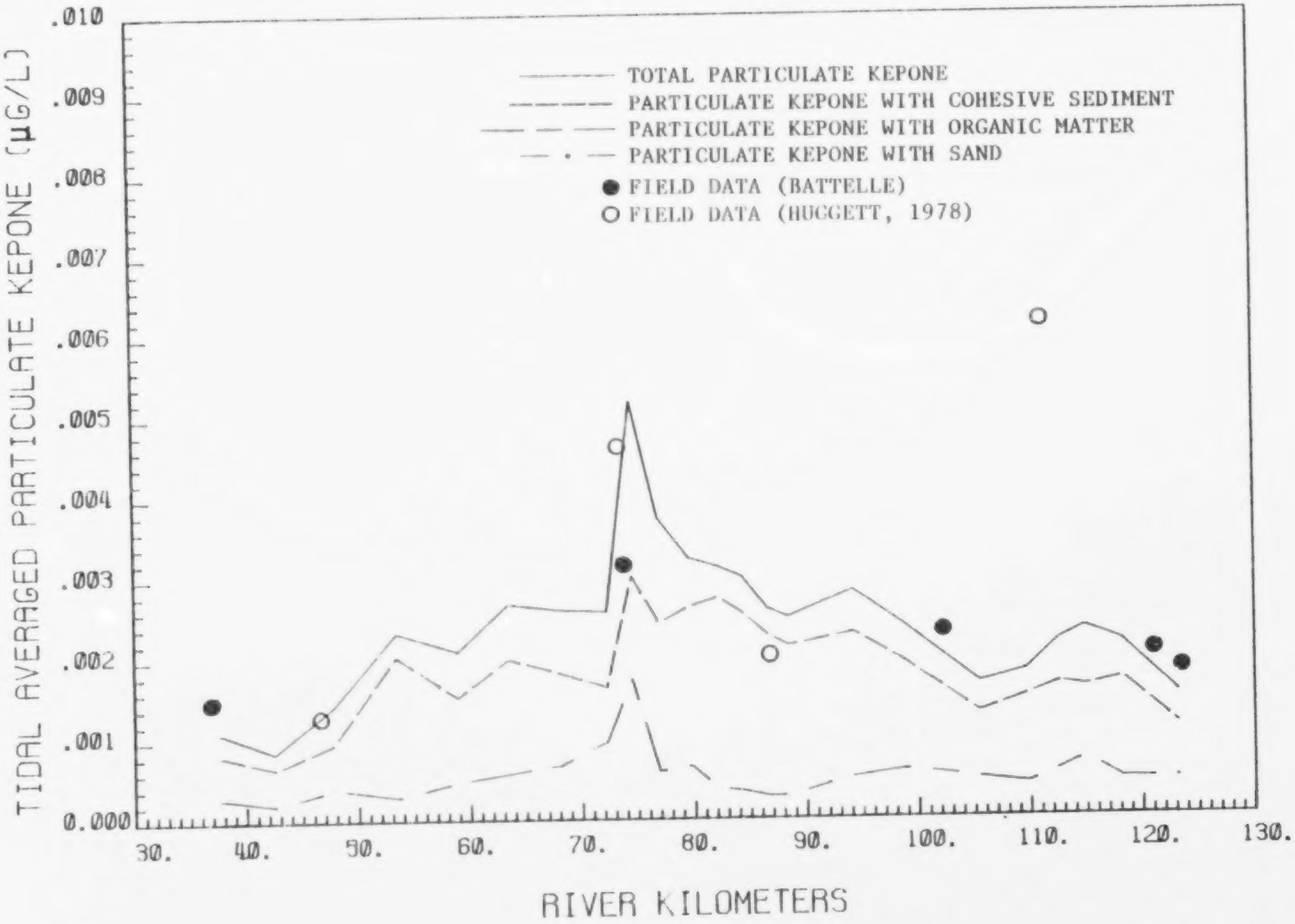


FIGURE M.26. Longitudinal Distributions of Tidal Averaged Particulate Kepone Concentrations per Unit Volume of Water for the Fresh-water Discharge of 58.3 m^3/sec

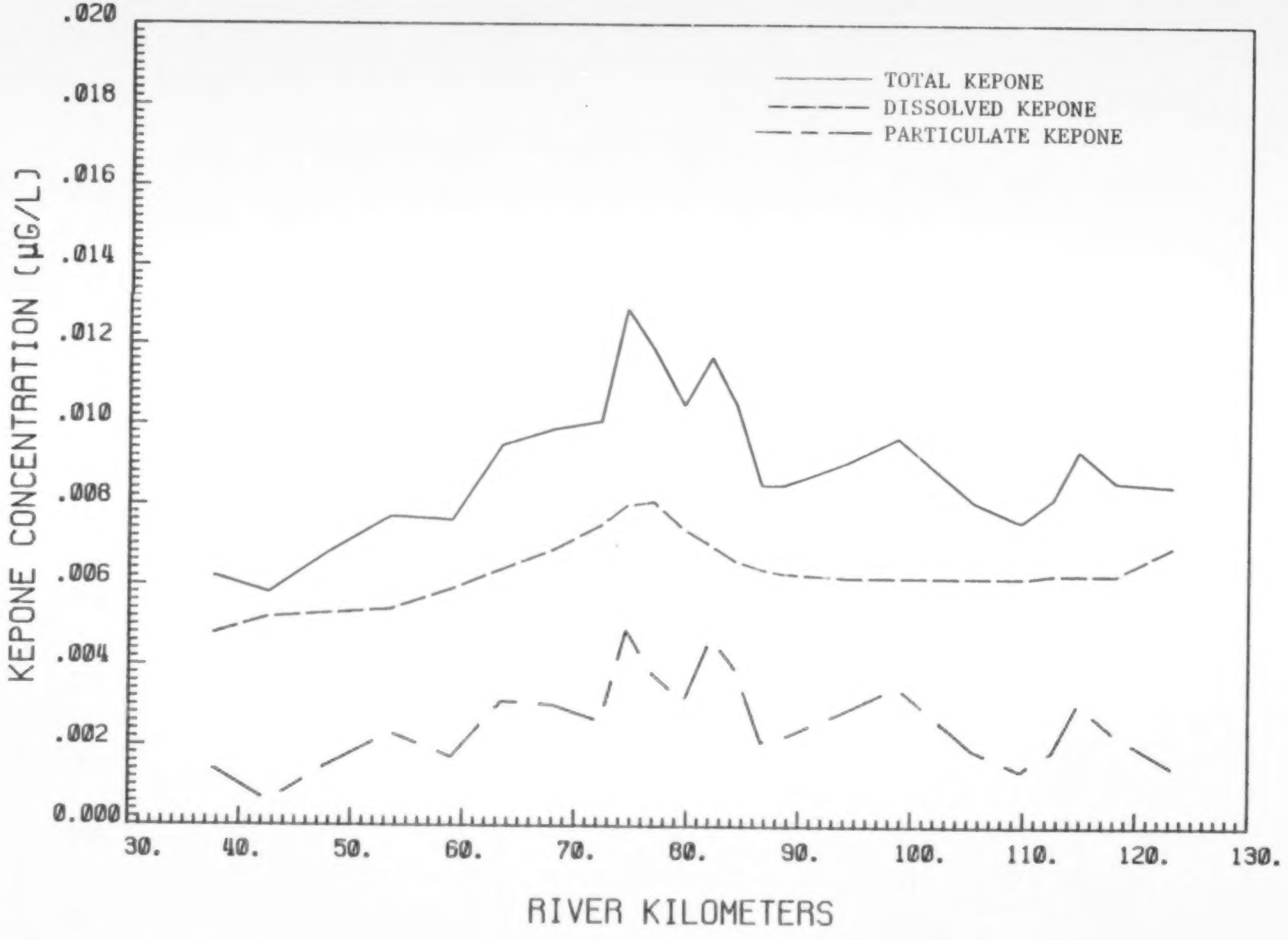


FIGURE M.27. Longitudinal Distributions of Total, Dissolved and Particulate Kepone Concentrations at Maximum Ebb Tide for the Fresh-water Discharge of 58.3 m^3/sec

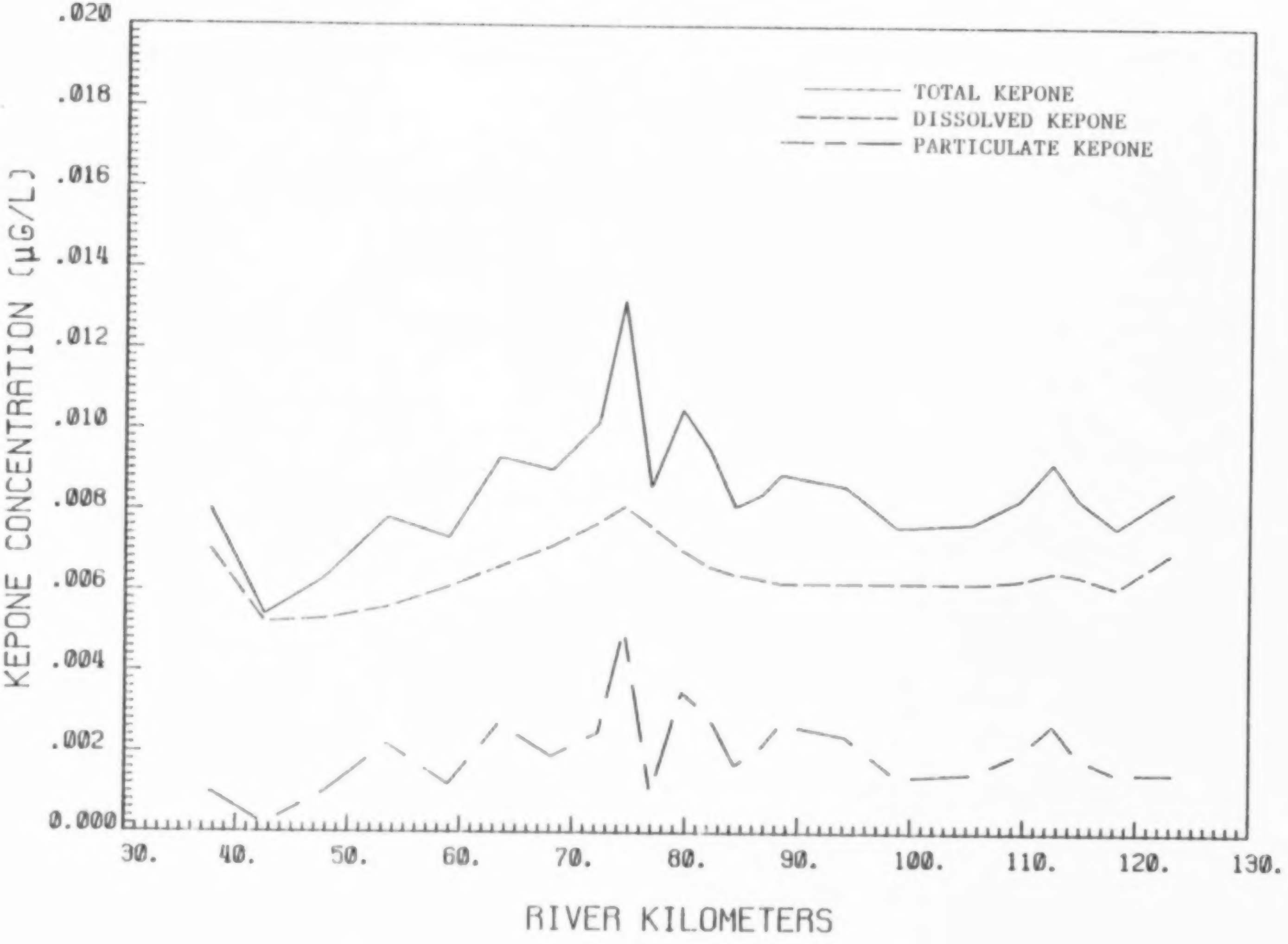


FIGURE M.28. Longitudinal Distributions of Total, Dissolved and Particulate Kepone Concentrations at Slack Tide for the Fresh-water Discharge of 58.3 m^3/sec

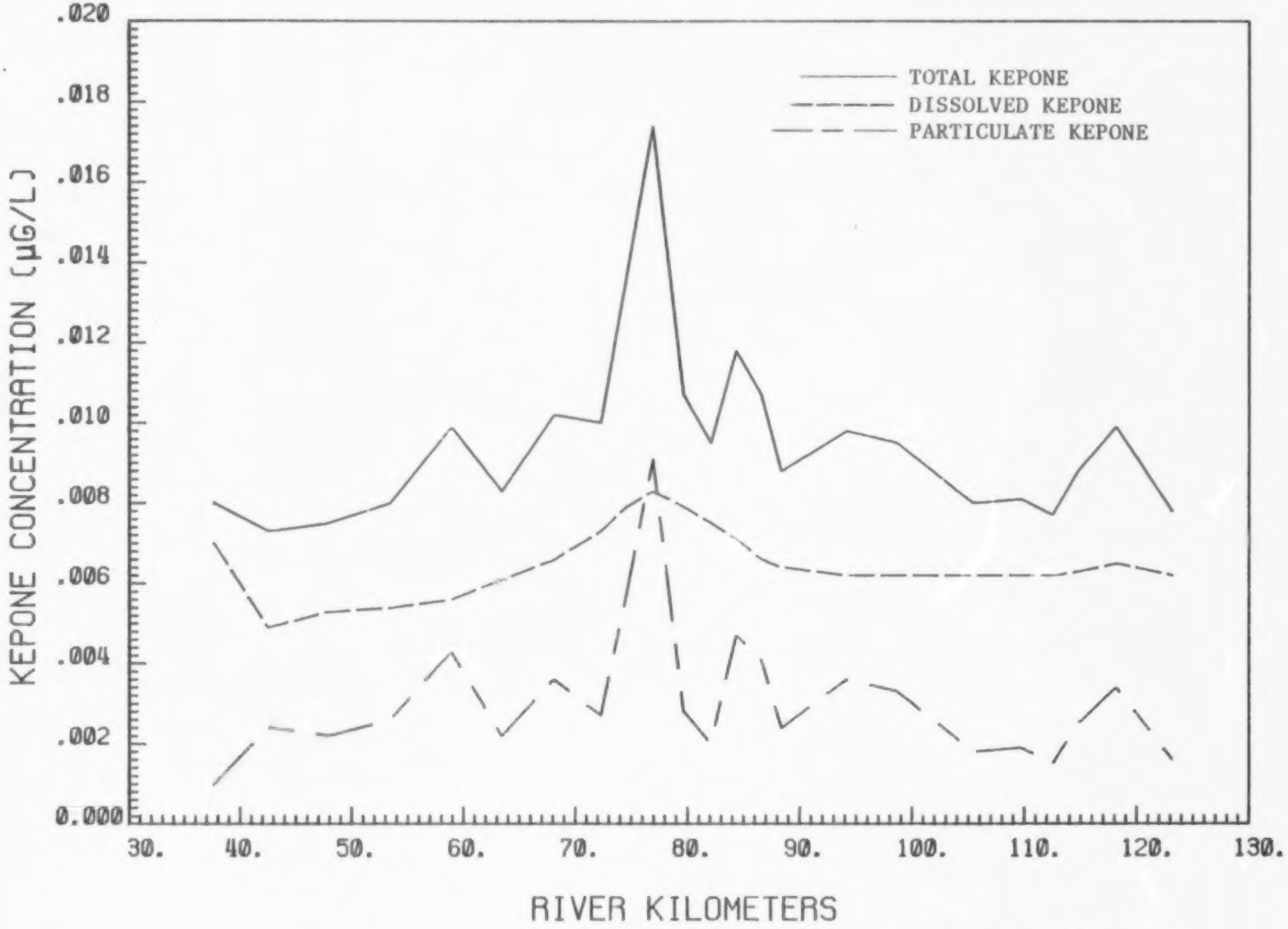


FIGURE M.29. Longitudinal Distributions of Total, Dissolved and Particulate Kepone Concentrations at Maximum Flood Tide for the Fresh-water Discharge of 58.3 m^3/sec

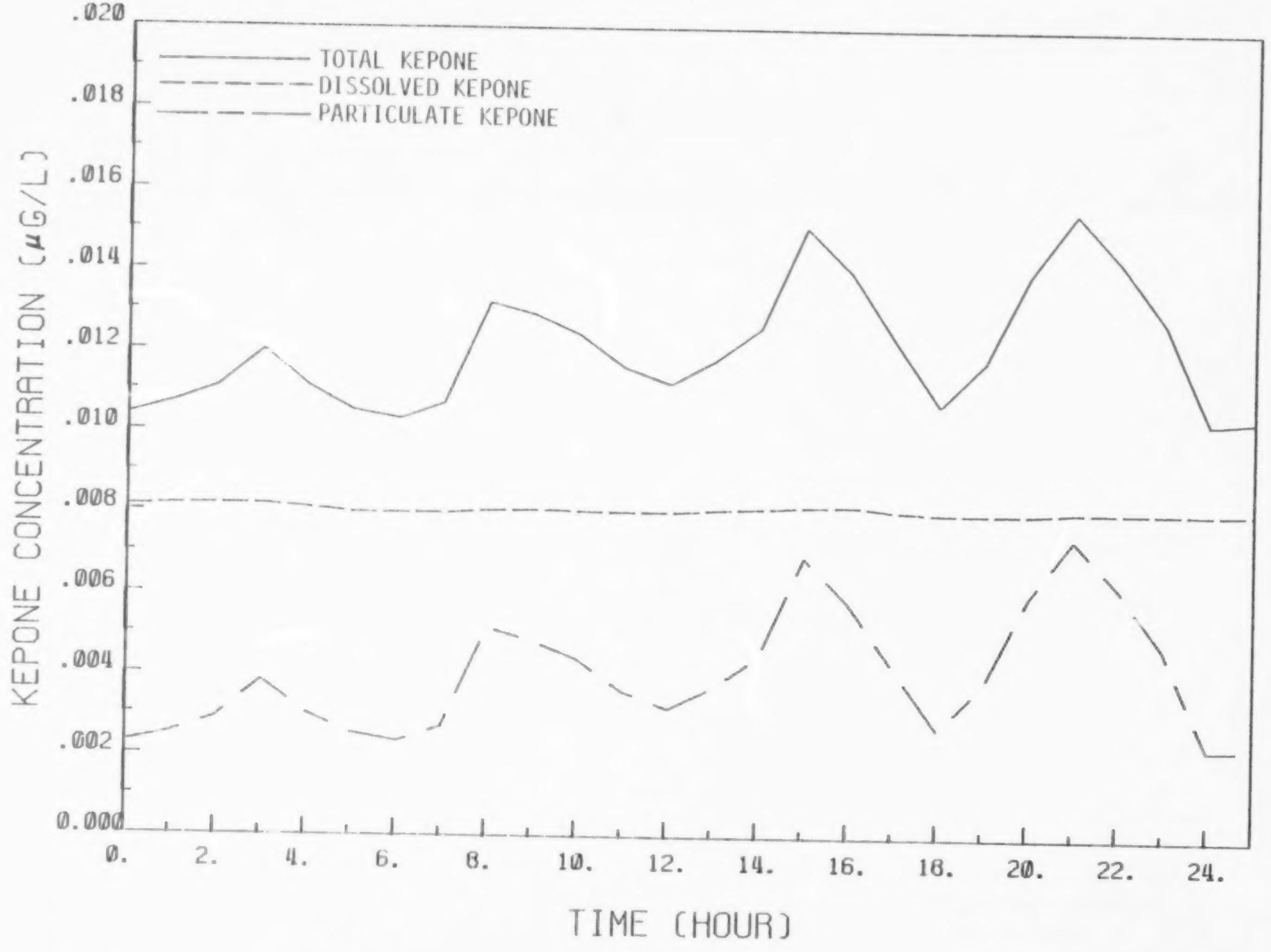


FIGURE M.30. Changes of Total, Dissolved and Particulate Kepone Concentration with Time at River Kilometer 75.7 for the Fresh-water Discharge of 58.3 m^3/sec

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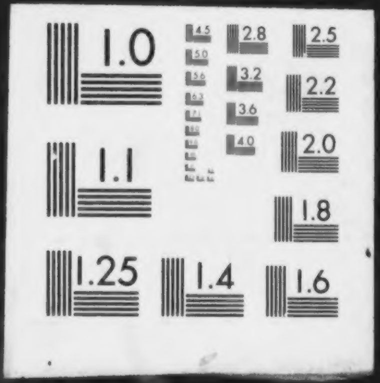

1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

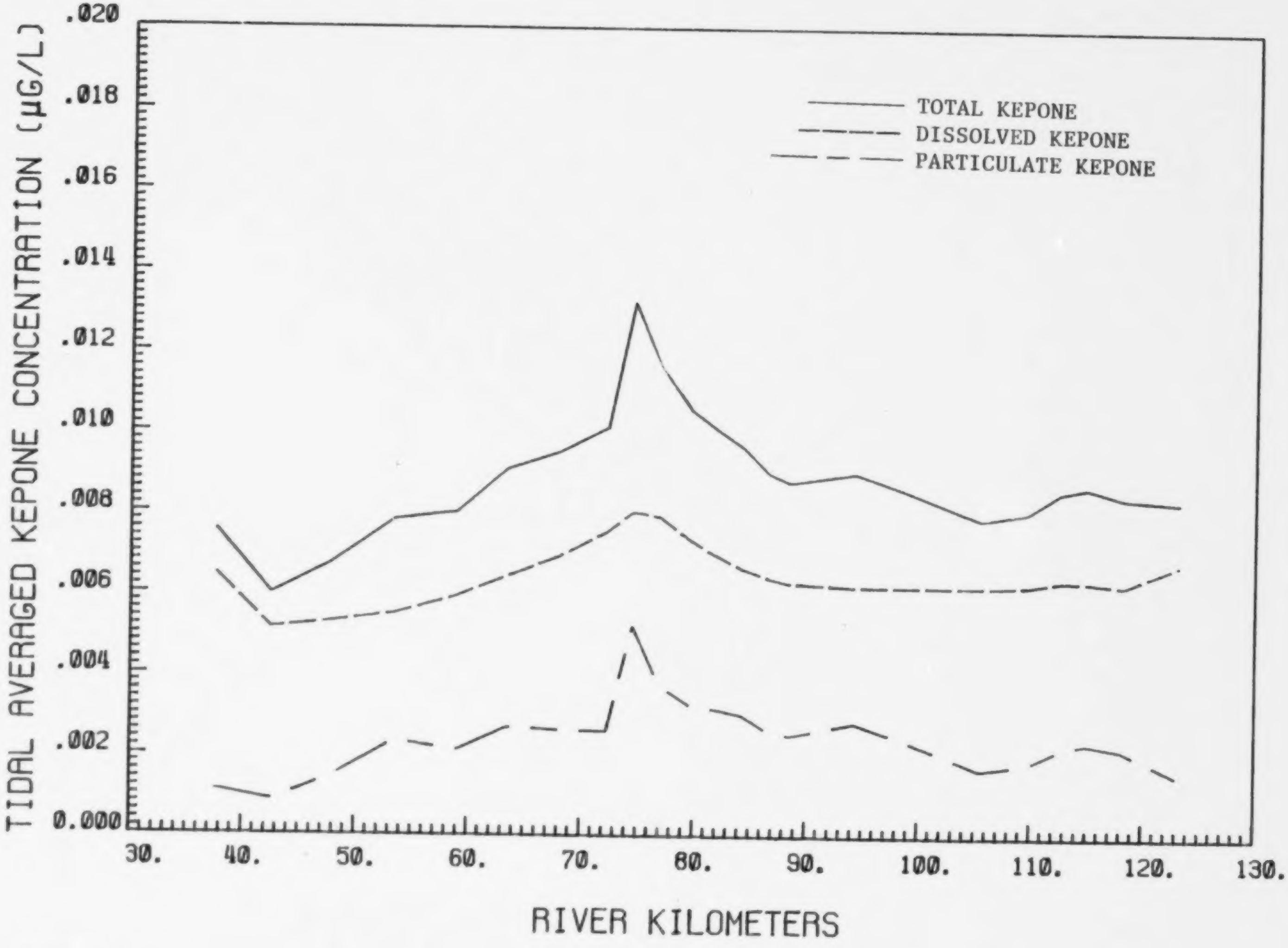

FIGURE M.31. Longitudinal Distributions of Tidal Averaged Total, Dissolved and Particulate Kepone Concentrations for the Fresh-water Discharge of 58.3 m^3/sec

At slack tide, only 13% of the total Kepone is associated with suspended sediment and 87% is the dissolved Kepone, due to settling of the suspended sediment during slack tide. At the maximum flood, bottom sediment is again resuspended and 54% of the total Kepone is being transported by sediment and 46% is the dissolved Kepone. When these values are tidally averaged, 32% of the total Kepone is associated with sediment, while 68% remains in water at this location. Changes of total, dissolved and particulate Kepone concentrations with time at River Kilometer 75.7 are shown in Figure M.30. As shown in this figure, dissolved Kepone concentration does not change significantly with time. However, particulate and thus total Kepone concentration changes with time due to the time dependency of sediment concentration.

The mathematical simulation results also reveal that at Burwell Bay, the tidal averaged total Kepone concentration is 0.0076 µg/ℓ and that approximately 14.0 kg of Kepone per year is transported from the tidal James River towards Chesapeake Bay. Dissolved and particulate Kepone concentrations are 0.0064 µg/ℓ and 0.0012 µg/ℓ, respectively. Hence, suspended sediment carries approximately 2.2 kg of Kepone per year seaward from the tidal James River while 11.8 kg of Kepone is transported from Burwell Bay each year in a dissolved form. Since there is some possible deposition of contaminated sediment and adsorption of dissolved Kepone by cleaner suspended sediment between Burwell Bay and the river mouth, 14.0 kg/yr is a conservative estimate.

Accumulated bed elevation changes after 1-month simulation are shown in Figure M.32. In this figure positive values along the vertical axis indicate the amount of sediment deposition in mm, during a 1-month simulation, while negative values show the amount of river bed scoured during the same period. This figure reveals a series of scouring and deposition patterns reflecting the complex geometry of the tidal James River with many bays being connected by narrow channels. For this flow case, an average annual net bed deposition rate for the 86-km tidal James River reach is predicted to be approximately 1.7 mm/yr.

Figure M.33 shows the change in bed surface Kepone concentration which occurs during a 1-month simulation. The Kepone concentrations shown here are those which occur on the very surface of the river bed without any mixing with the Kepone below that level. For example, in Bailey Bay (around River Kilometer 120) Kepone concentrations is reduced dramatically during a 1-month simulation. As shown in Figure M.32, Bailey Bay experienced sediment deposition of approximately 2 mm. Figure M.33 indicates that the Kepone concentration in this top 2-mm layer is reduced from the level shown in the solid line to that shown in the dotted line. Another example is around the 70-River Kilometer area. Figure M.32 reveals that there is a net scour of approximately 1 mm. Hence, the Kepone concentration in the very surface of the river bed after 1-month simulation shown in Figure M.33 is the one that appeared in the layer as it existed 1 mm below the original bed surface. Figure M.33 reveals a definite trend of reducing the Kepone level near the upper part of the river and of increasing the level near the lower part of the river.

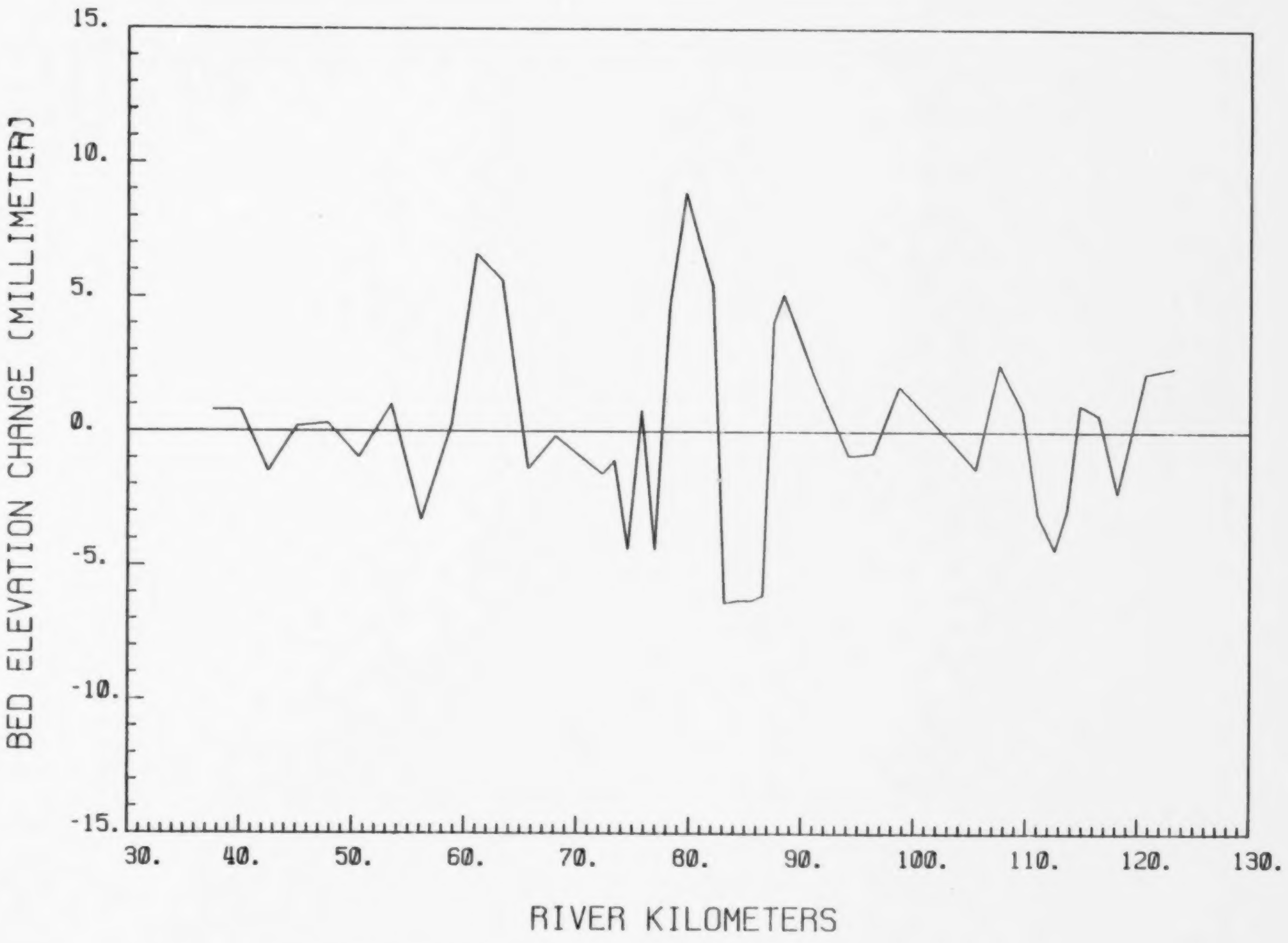

FIGURE M.32. Variation of River Bed Elevation Changes Due to Sediment Deposition and/or Bed Scouring at Maximum Ebb Tide for the Fresh-water Discharge of 58.3 m^3/sec

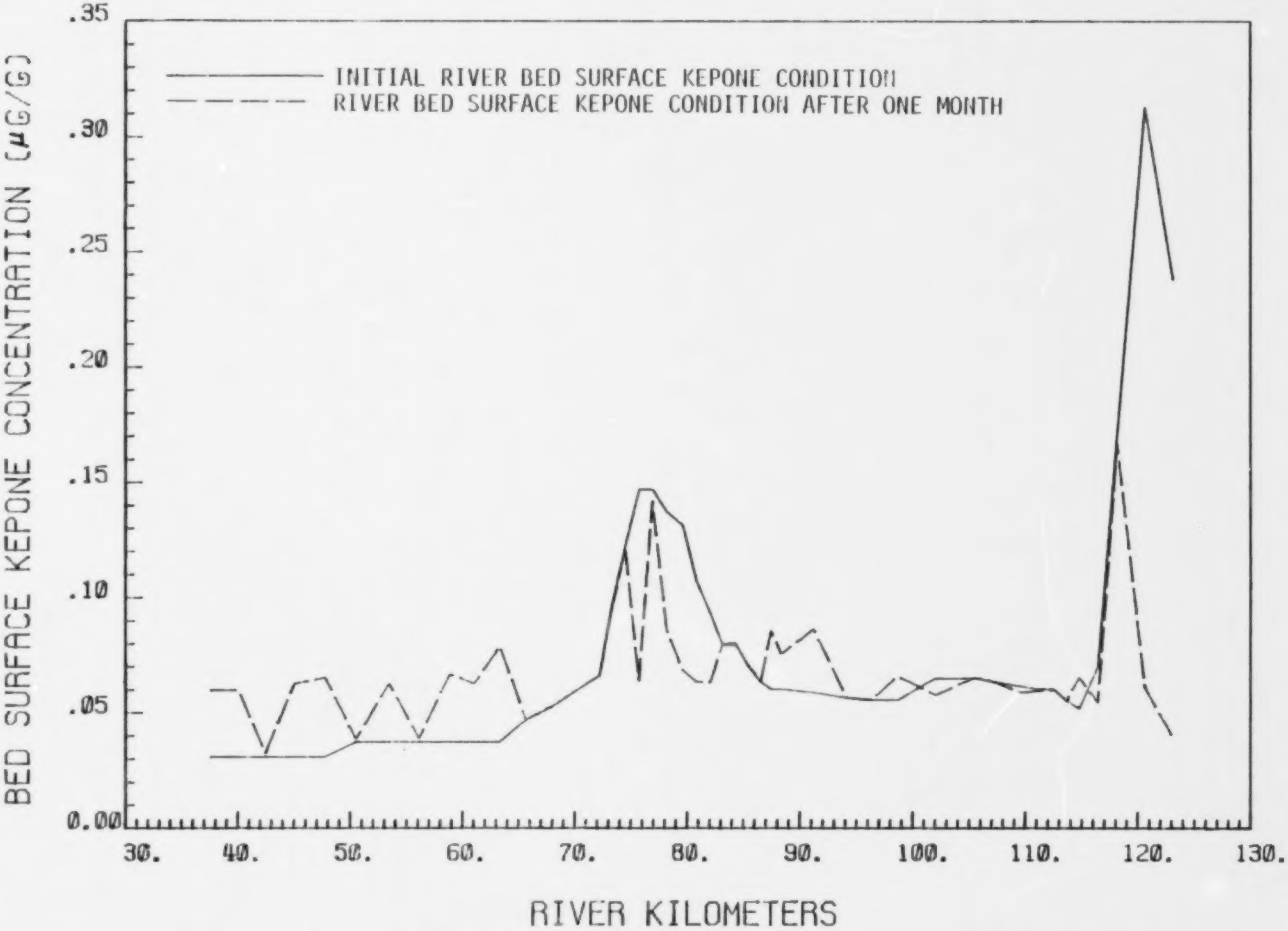

FIGURE M.33. Change on Bed Surface Kepone Concentration Occurred During 1-Month Simulation for the Fresh-water Discharge of 58.3 m^3/sec

Case 2 - Net Fresh-water Discharge of 247 m^3/sec

Computed longitudinal distributions of flow velocities at the three tidal stages, maximum ebb, slack and maximum flood are shown in Figure M.34. Figures M.35 through M.37 present computed longitudinal variations of cross-sectional averaged depth of the tidal James River at the three tidal stages, respectively.

Longitudinal distributions of sediment concentrations at maximum ebb, slack and maximum flood tides are shown in Figures M.38 through M.40, respectively. The tidal averaged sediment concentrations are shown in Figure M.41. These figures include sediment concentrations of each type of sediment (cohesive sediment, organic material or sand) and total sediment (sum of those sediment components). Measured total sediment concentrations obtained by Nichols (1972) in March 1965 and March 1960 are also plotted for the purpose of model verification. As discussed in Chapter VII, comparison of these field data with computer results at slack tide and tidal average cases (Figures M.39 and M.41) indicate excellent agreement among these values. Computer results shown in Figures M.38 through M.40 reveal that there are two peaks of the total sediment distribution with both having approximately 100 mg/ℓ concentrations. One occurs between River Kilometer 75 and 95, and the other around River Kilometer 55. The former peak is produced due to extensive river bed souring in the vicinity of this reach and the latter is due to the existence of a clear null zone around the River Kilometer 50 (Nichols, 1972). The tidal averaged total sediment concentration shown in Figure M.41 indicates that the concentration varies from approximately 25 mg/ℓ to 100 mg/ℓ with an areawide average of 66.5 mg/ℓ. This figure also indicates that cohesive sediment is the dominant suspended sediment with 55.1 mg/ℓ of the areawide average concentration. This corresponds to 82.9% of the total sediment concentration. The second largest amount is organic matter having 11.0 mg/ℓ, which corresponds to 16.5% of the total sediment. Suspended sand has the smallest value of 0.4 mg/ℓ which is only 0.6% of the total sediment concentration. As compared to Case 1 (see Figure M.17), all three components of sediment increase their concentrations. Percentage of cohesive sediment to the total sediment for Case 2 decreases from 87.0 to 82.9%. On the other hand, organic matter increases its contribution from 12.4 to 16.5%. Sand contribution remains the same at 0.6%.

Distributions of particulate Kepone at the three tidal stages are shown in Figures M.42 through M.44 while tidal averaged distributions are presented in Figure M.45. The tidal averaged particulate Kepone distribution, as shown in Figure M.45, indicates that the total particulate Kepone concentration changes from 0.040 μg/g to 0.098 μg/g with the overall average of 0.070 μg/g. The peak concentrations occurs at approximately River Kilometer 75. Overall particulate Kepone concentrations associated with suspended cohesive sediment, organic matter and sand are 0.060, 0.120, and 0.006 μg/g, respectively.

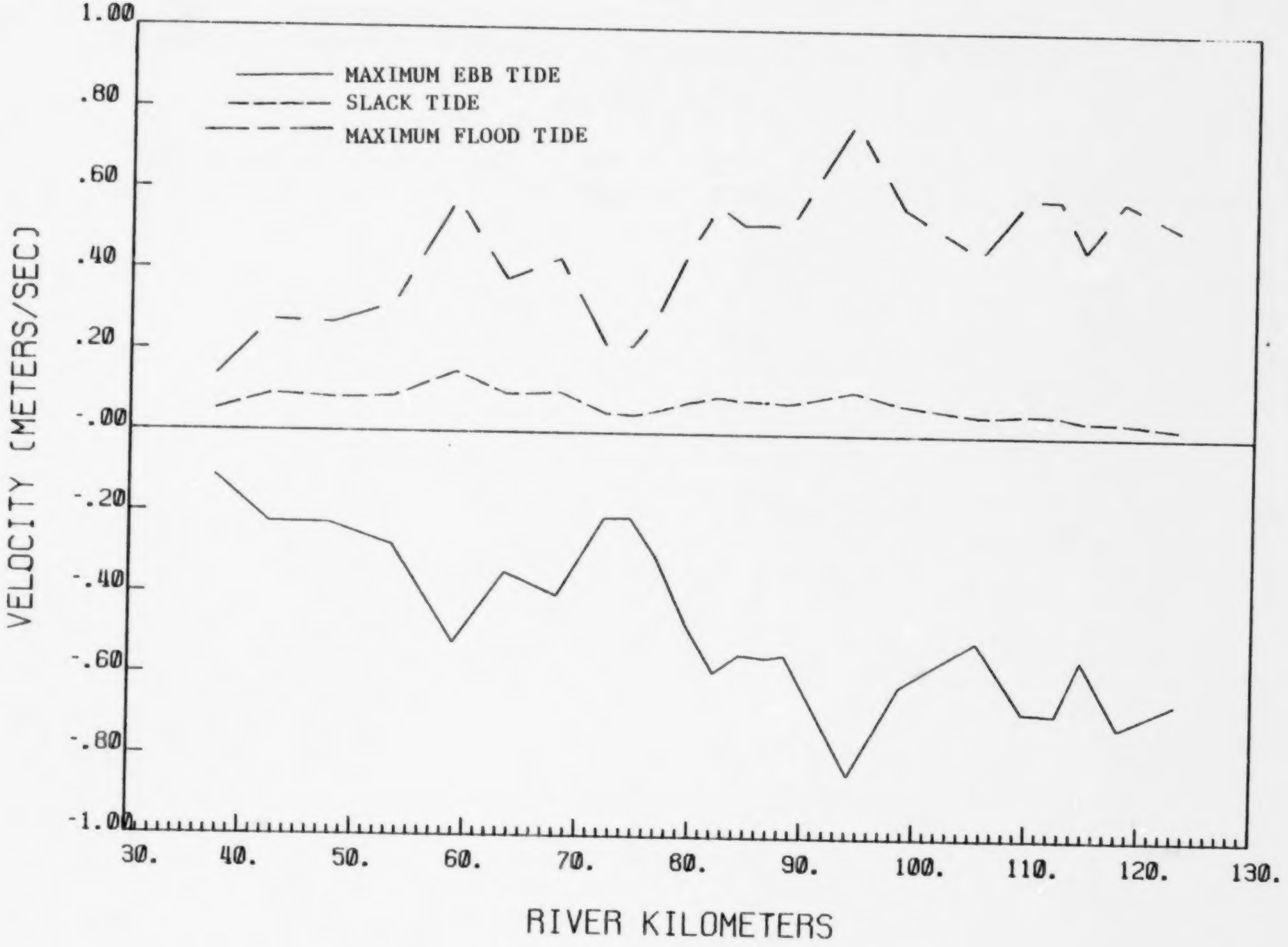

FIGURE M.34. Longitudinal Velocity Distributions at Maximum Ebb, Slack and the Maximum Flood Tides for Fresh-water Input Discharge of 247 m^3/sec

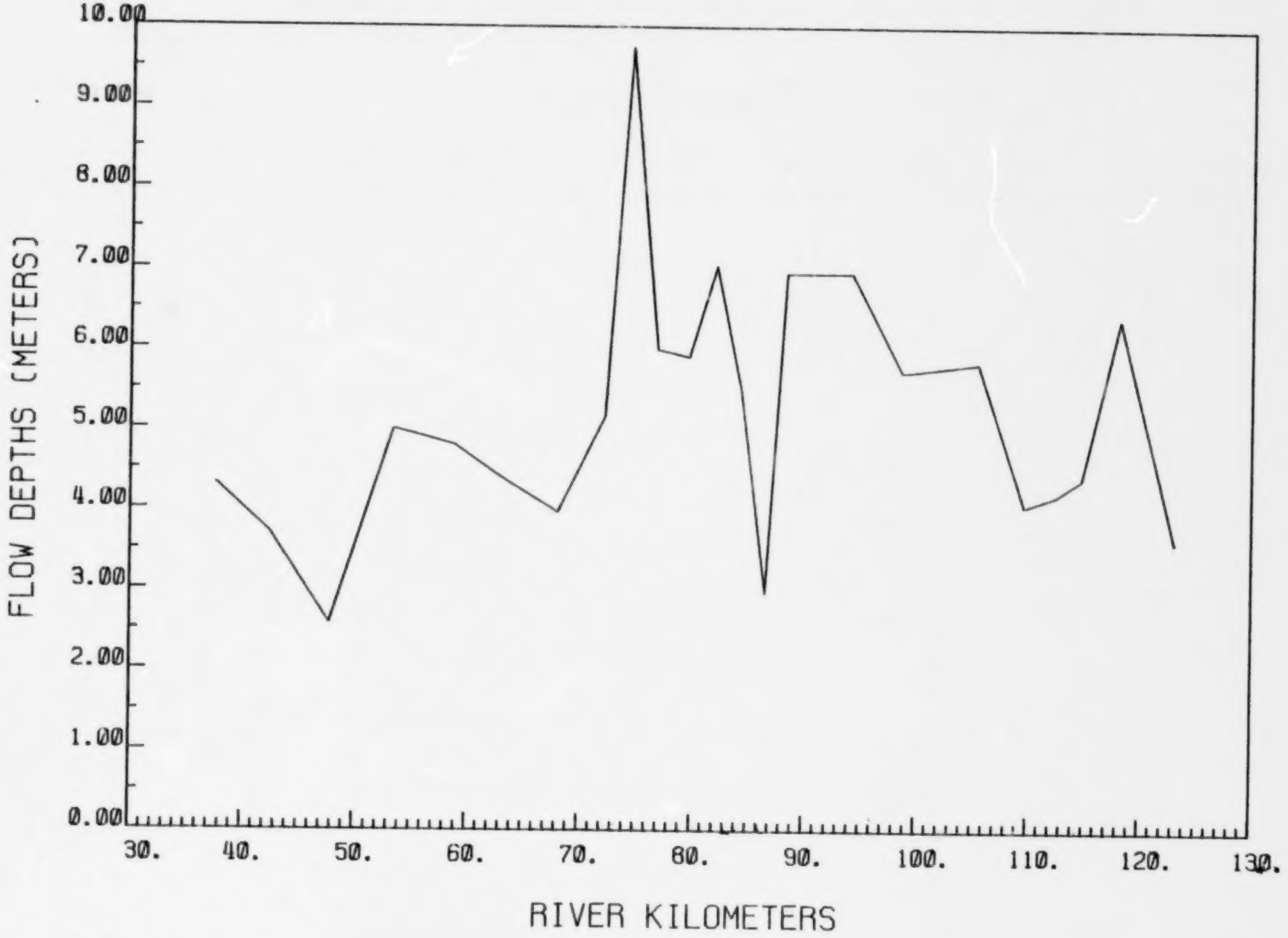

FIGURE M.35. Longitudinal Depth Variation at Maximum Ebb Tide for the Fresh-water Discharge of 247 m^3/sec

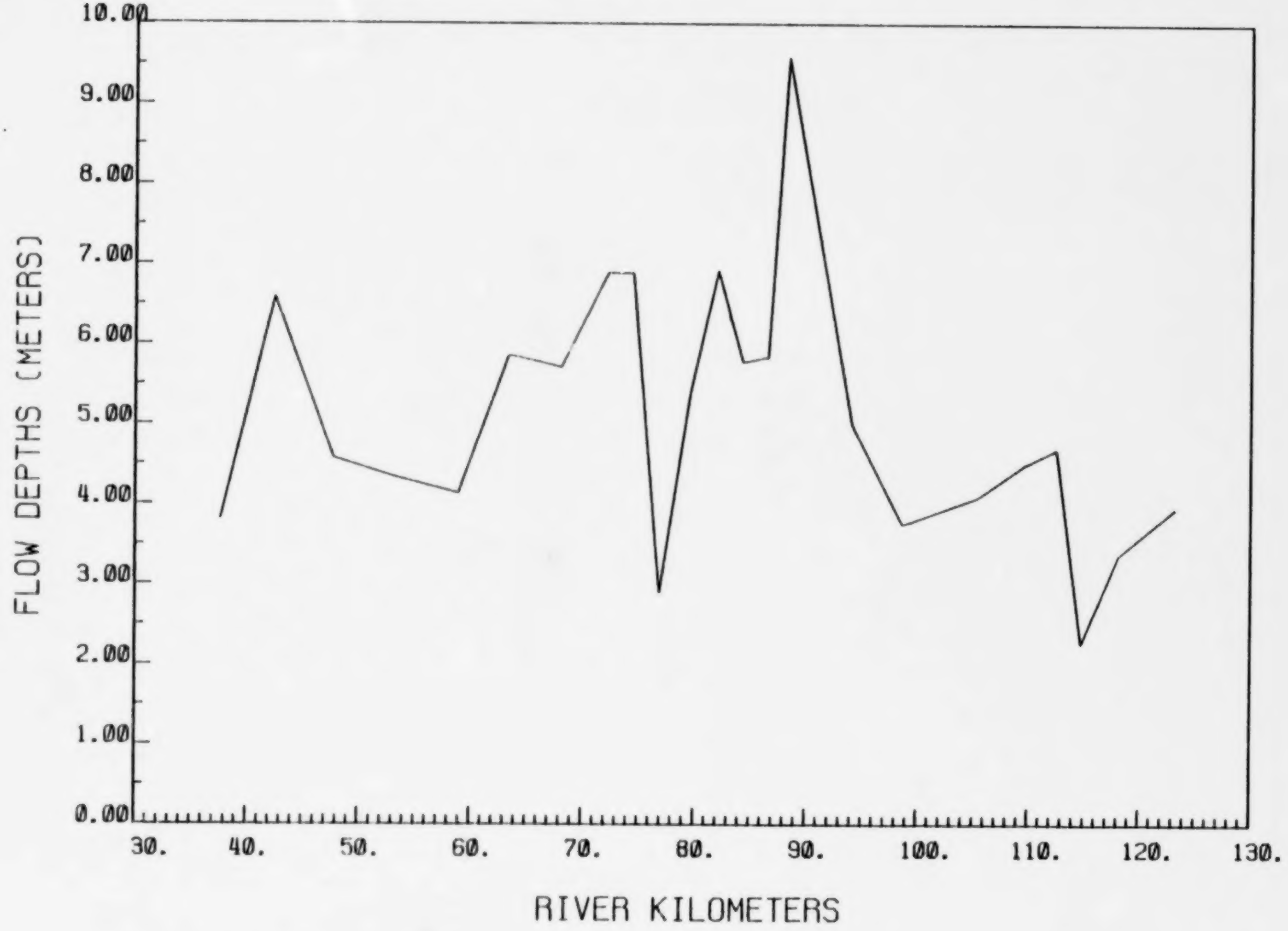

FIGURE M.36. Longitudinal Depth Variation at Slack Tide for the Fresh-water Discharge of 247 m^3/sec

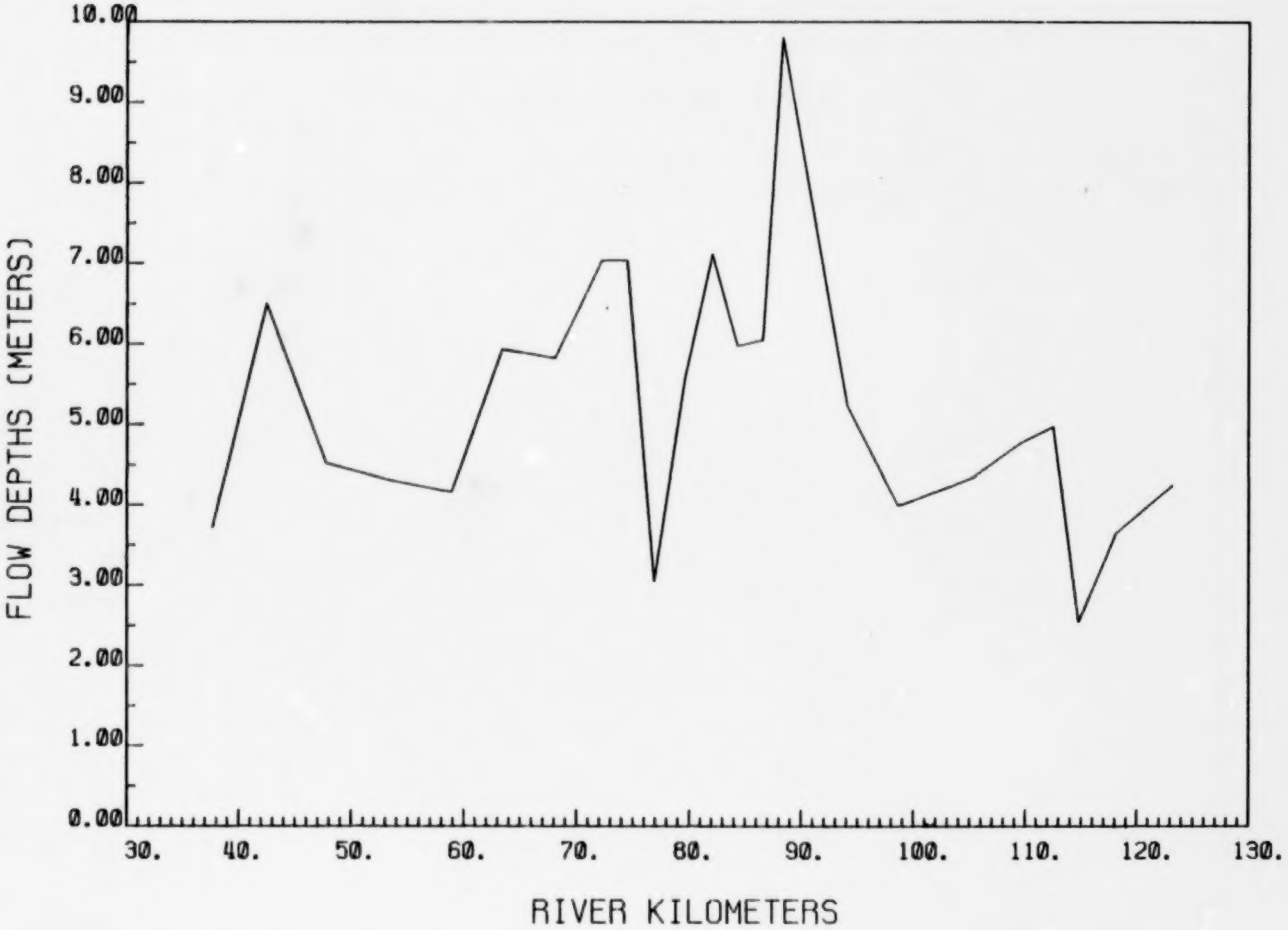

FIGURE M.37. Longitudinal Depth Variation at Maximum Flood Tide for the Fresh-water Discharge of 247 m^3/sec

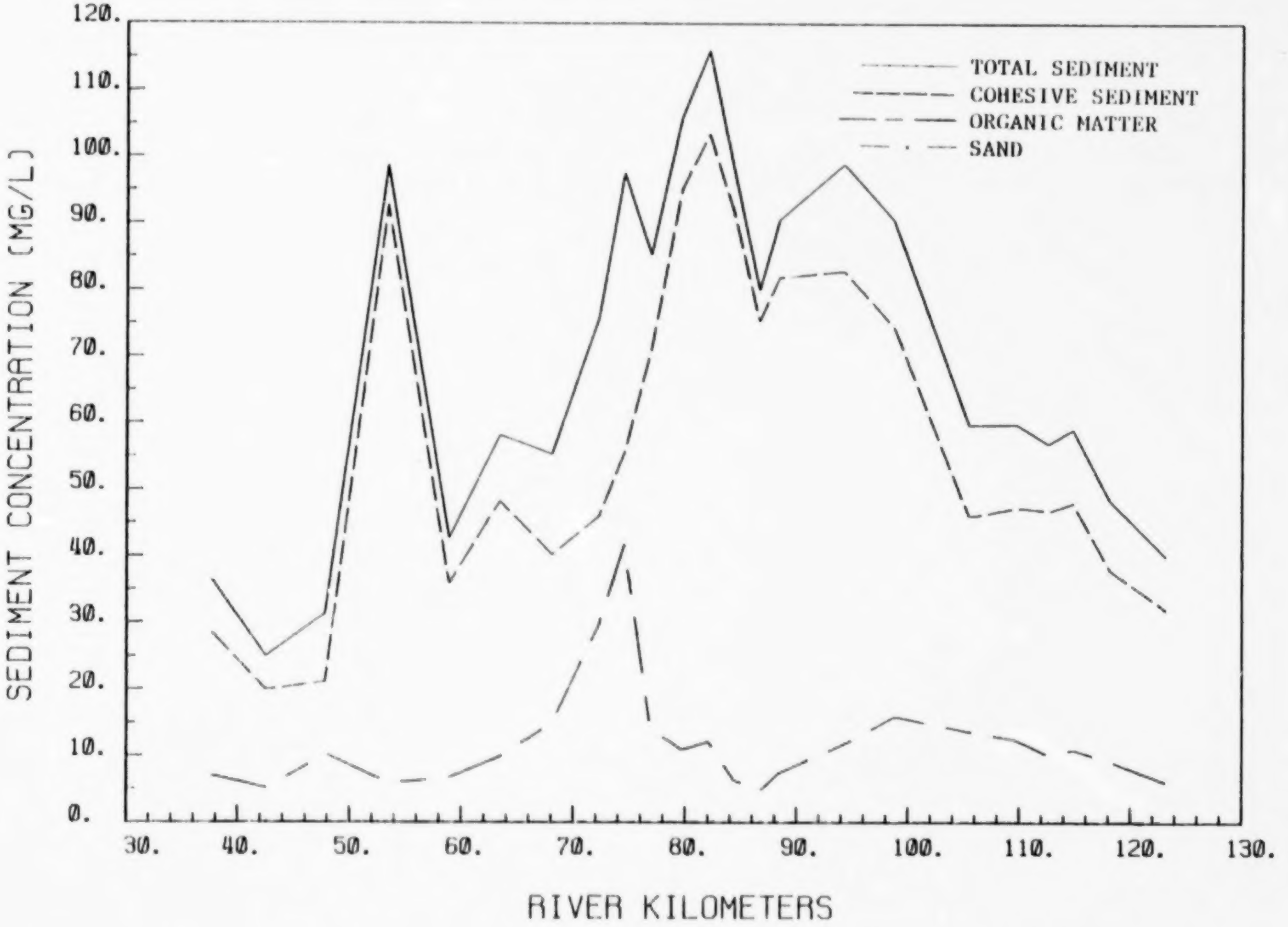

FIGURE M.38. Longitudinal Distribution of Sediment Concentration of Each Sediment Type at Maximum Ebb Tide for the Fresh-water Discharge of 247 m^3/sec

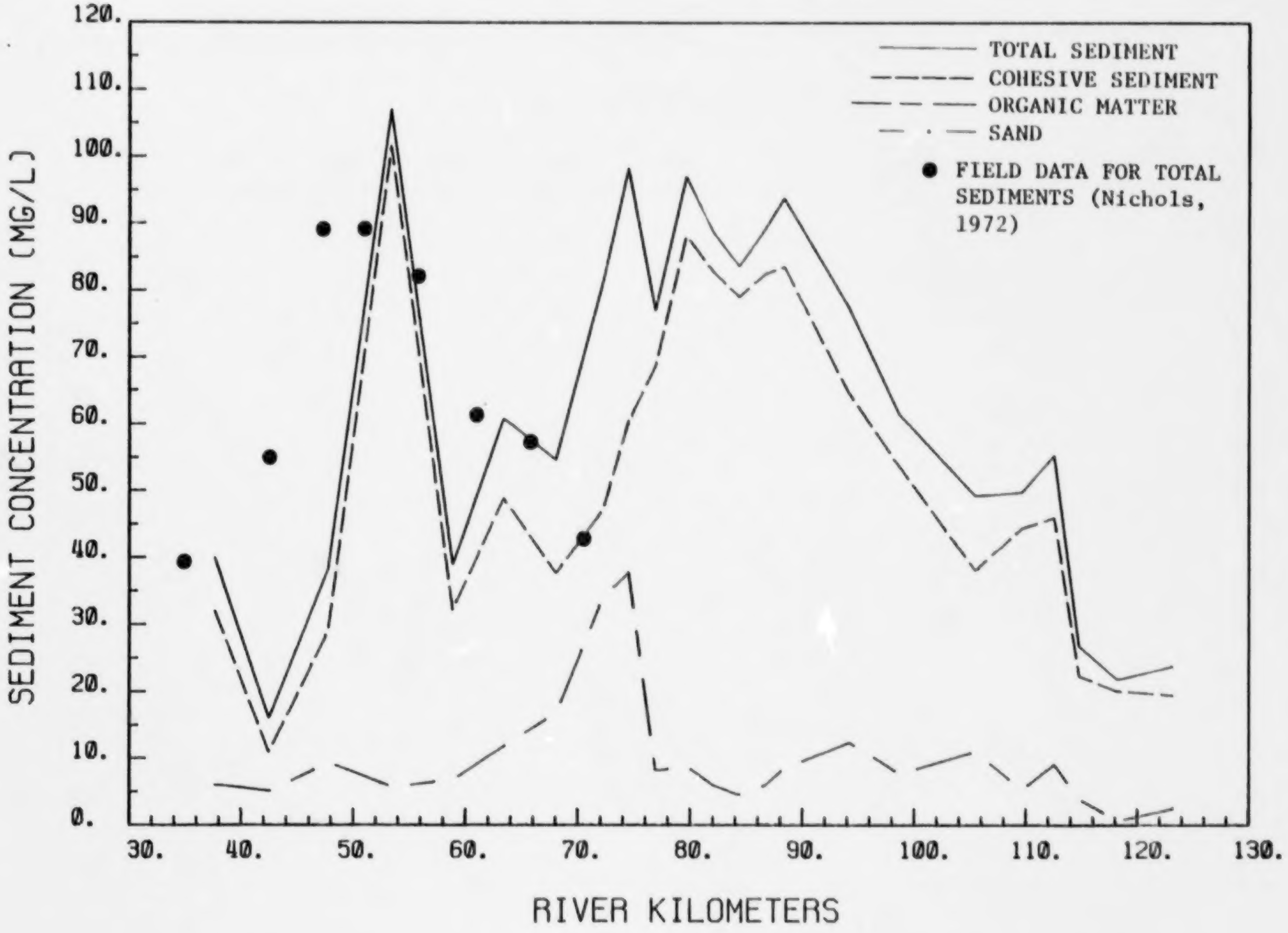

FIGURE M.39. Longitudinal Distribution of Sediment Concentration of Each Sediment Type at Slack Tide for the Fresh-water Discharge of 247 m^3/sec

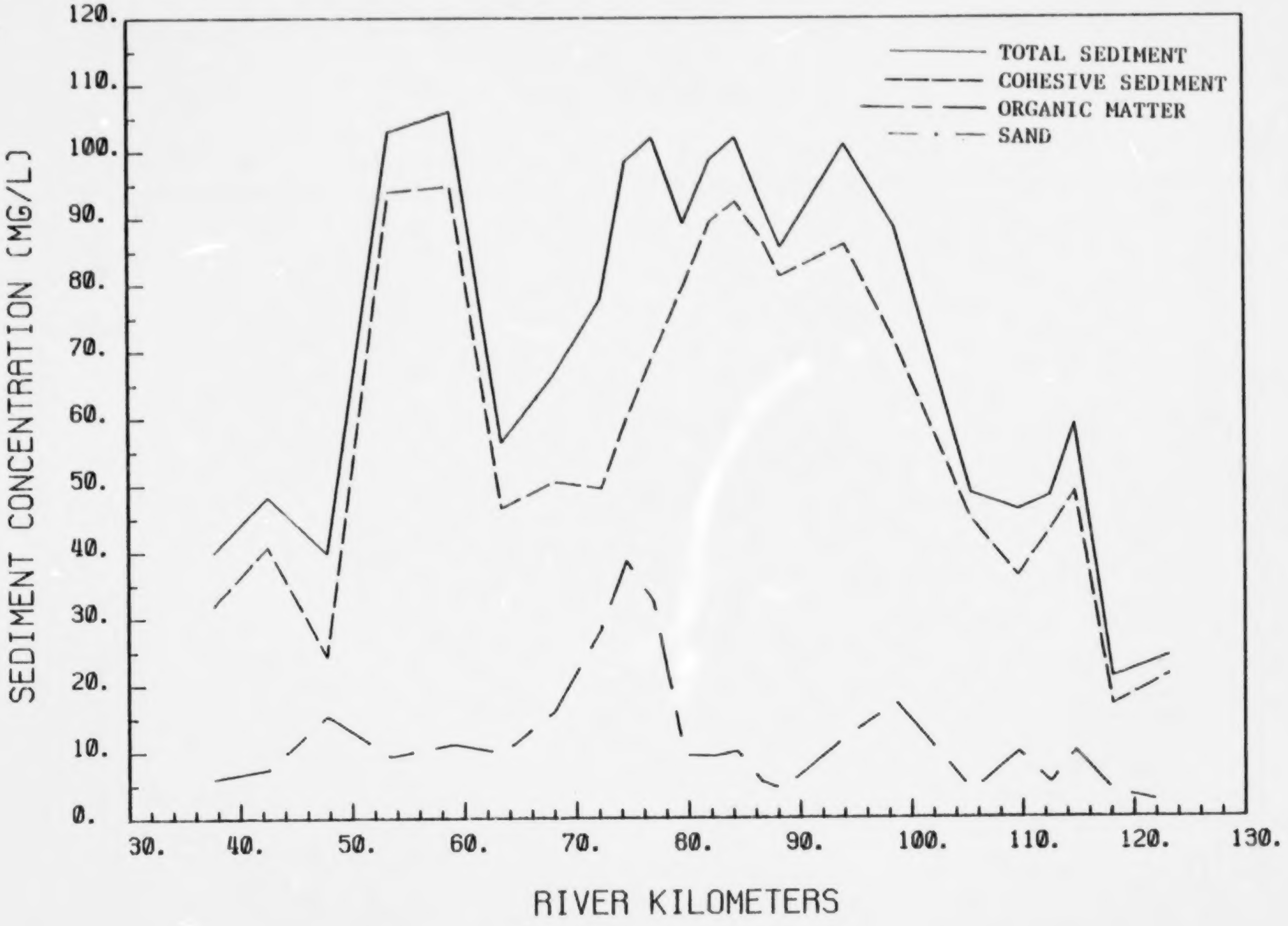

FIGURE M.40. Longitudinal Distributions of Sediment Concentration of Each Sediment Type at Maximum Flood Tide for the Fresh-water Discharge of 247 m^3/sec

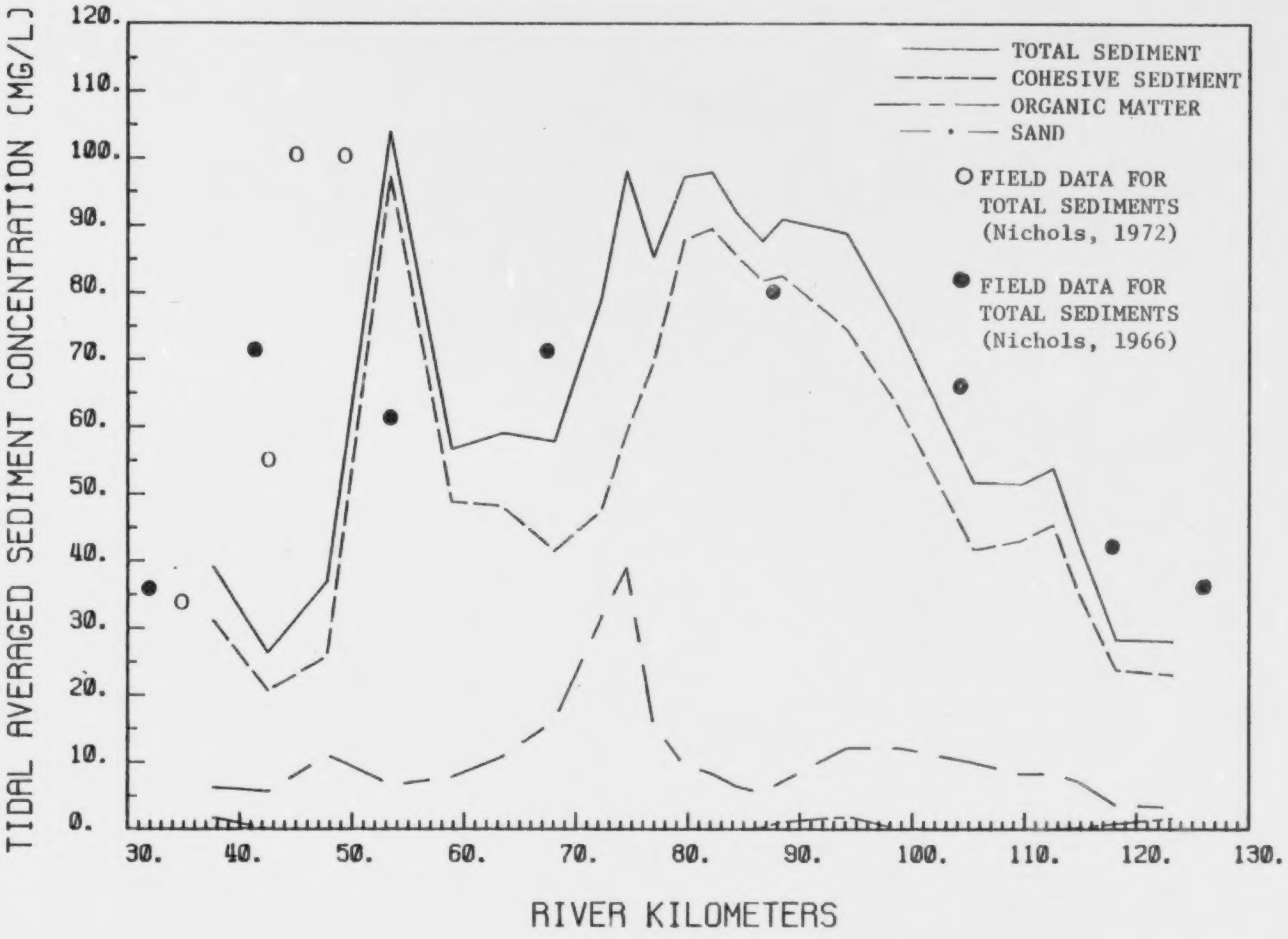

FIGURE M.41. Tidal Averaged Sediment Concentration of Each Sediment Type for the Fresh-water Discharge of 247 m^3/sec

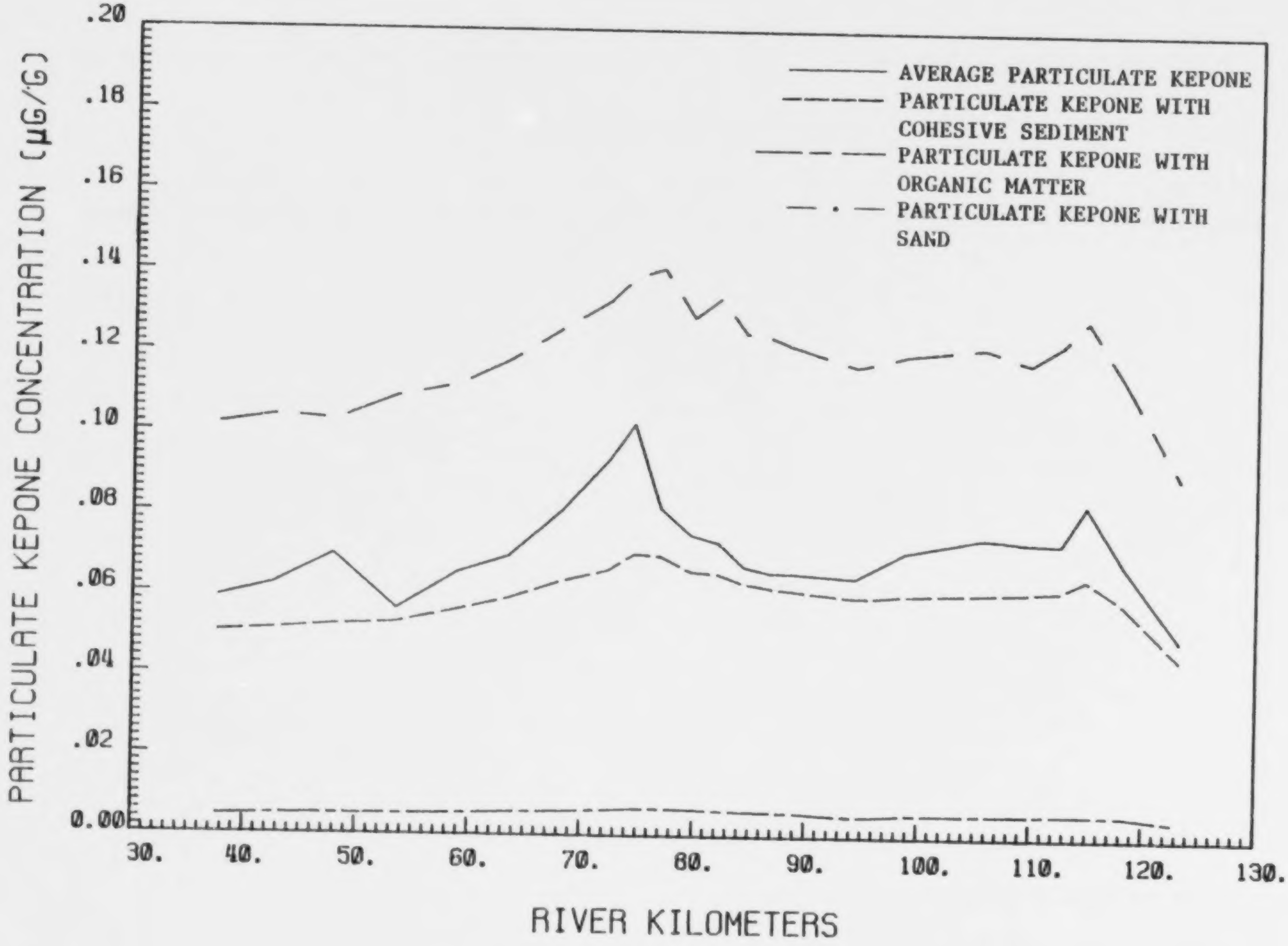

FIGURE M.42. Longitudinal Distributions of Particulate Kepone Concentrations at Maximum Ebb Tide for the Fresh-water Discharge to 247 m^3/sec

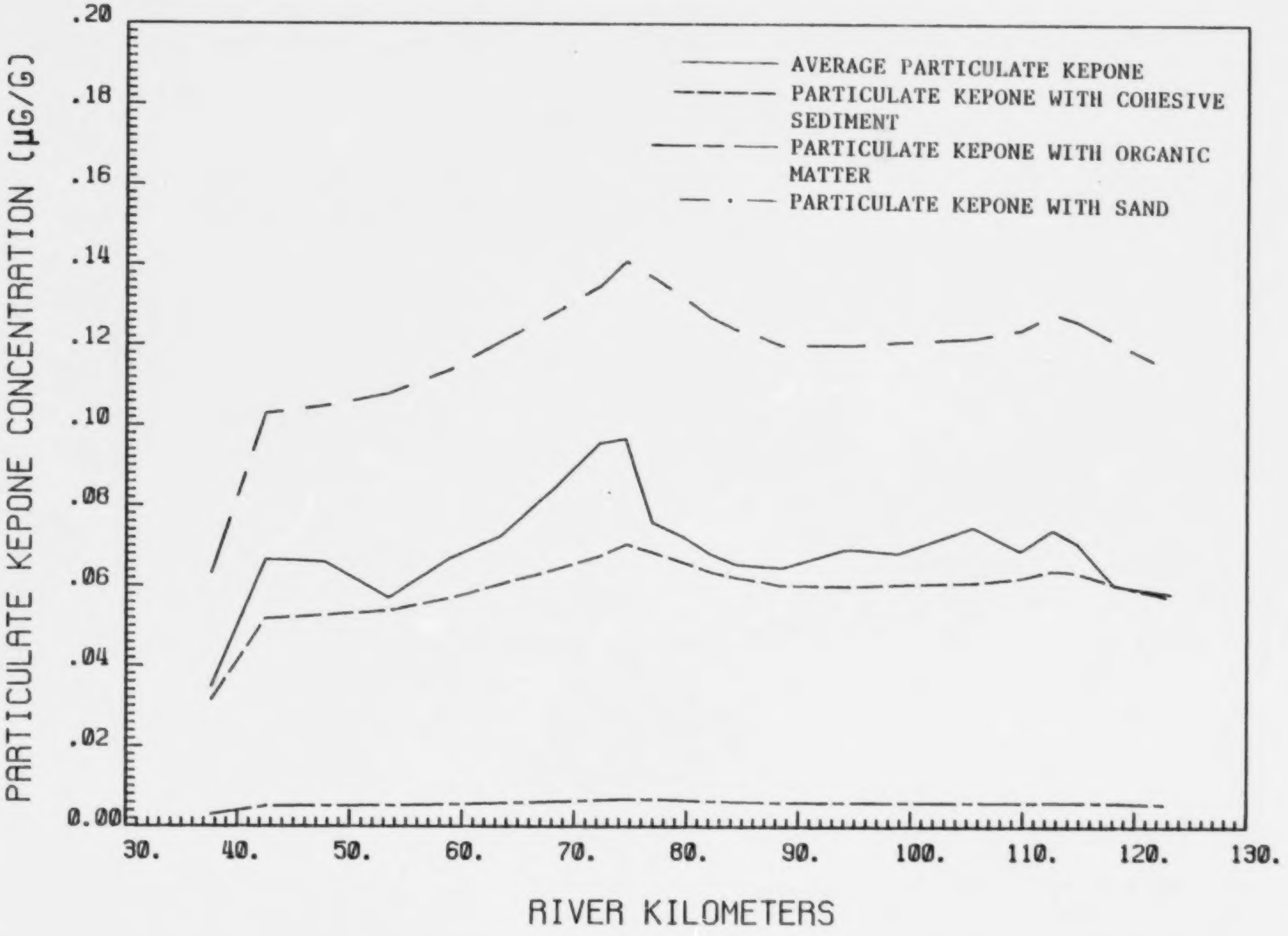

FIGURE M.43. Longitudinal Distributions of Particulate Kepone Concentrations at Slack Tide for the Fresh-water Discharge of 247 m^3/sec

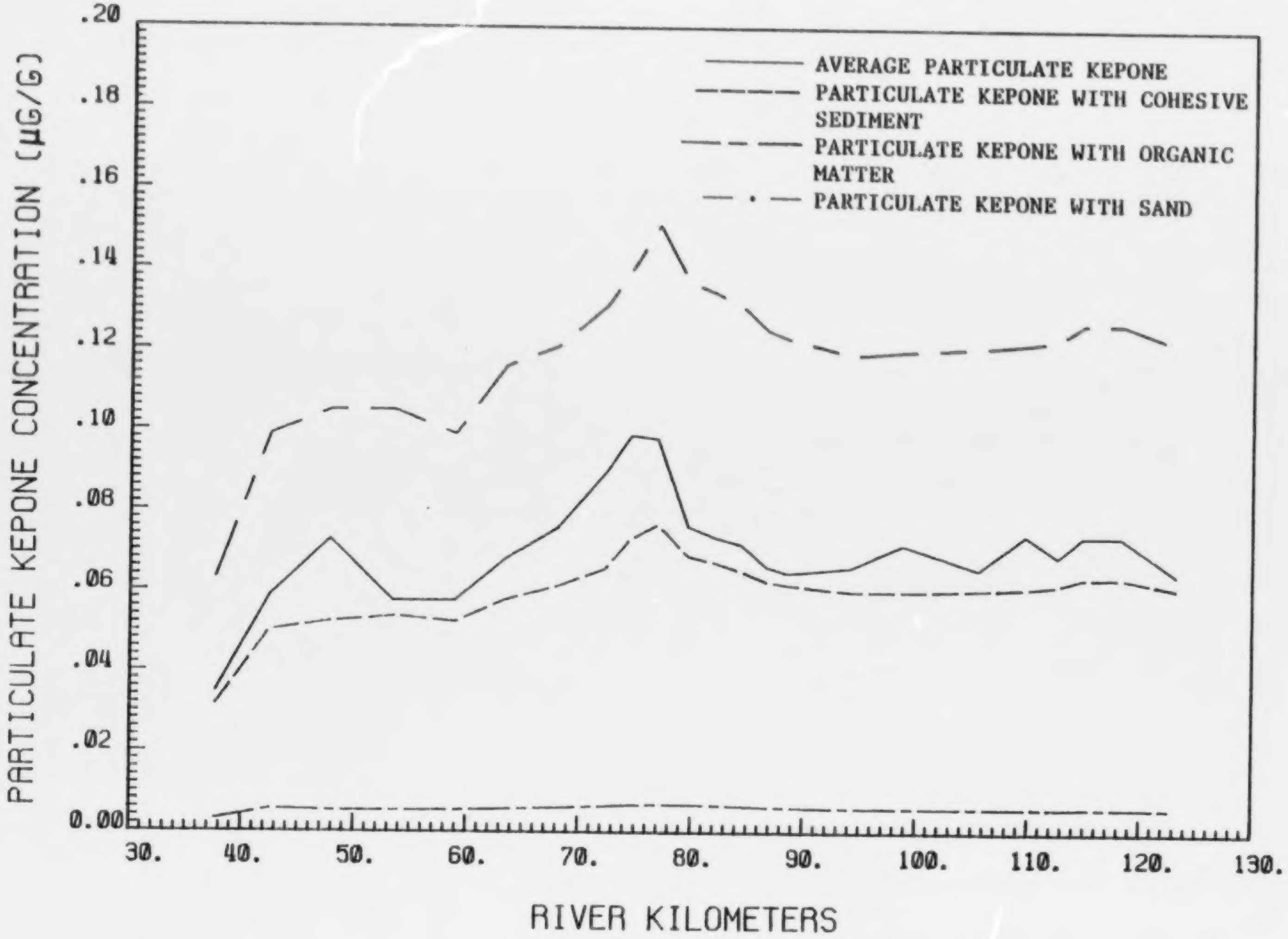

FIGURE M.44. Longitudinal Distributions of Particulate Kepone Concentrations at Maximum Flood Tide for the Fresh-water Discharge 247 m^3/sec

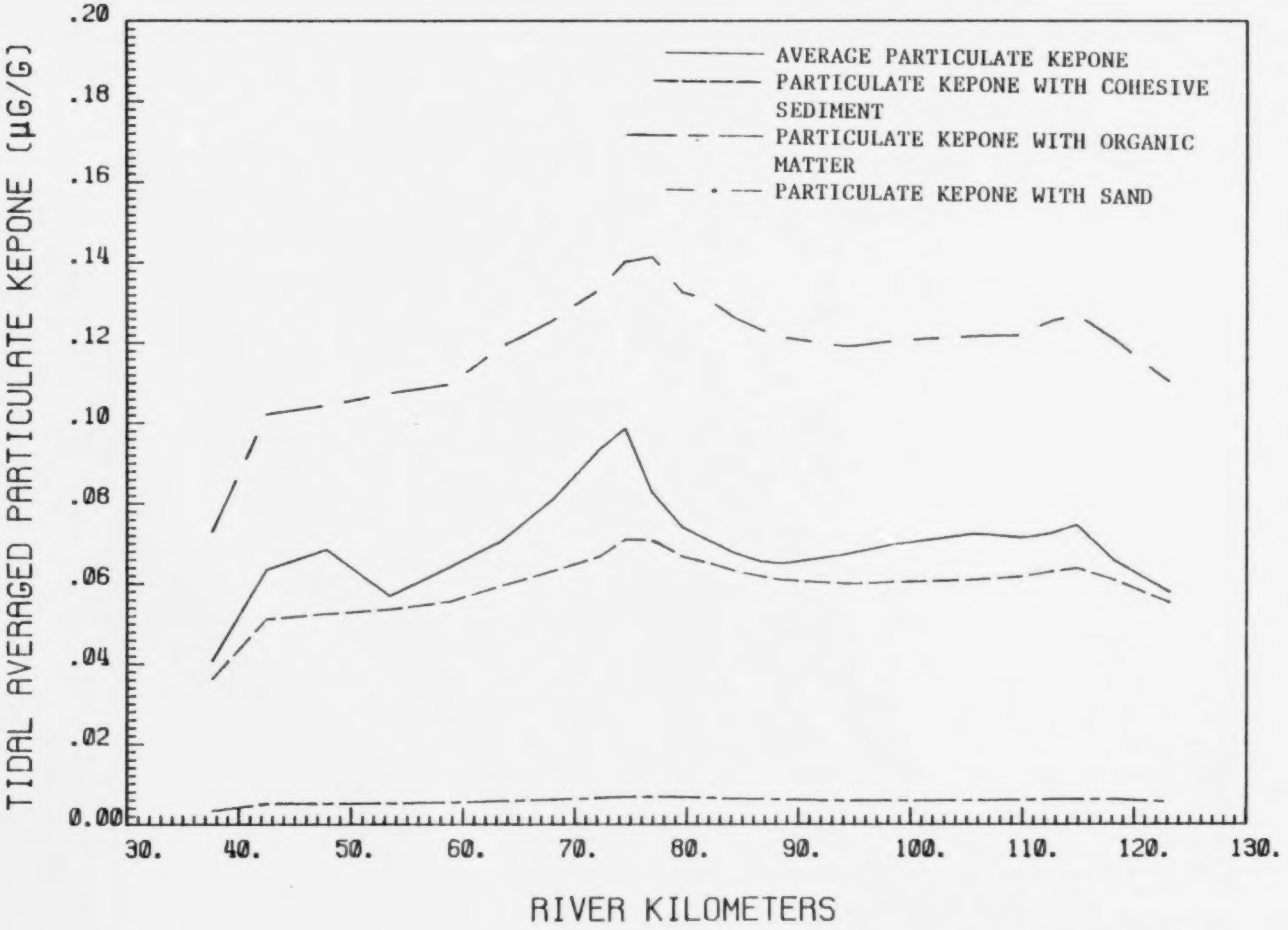

FIGURE M.45. Tidal Averaged Particulate Kepone Concentrations for the Fresh-water Discharge of 247 m^3/sec

Figures M.46 through M.48 show longitudinal distributions of particulate Kepone concentrations per unit volume of water, μg/ℓ. The tidal averaged distribution is presented in Figure M.49. These figures indicate that particulate Kepone concentration varies from 0.0015 μg/ℓ to 0.010 μg/ℓ with two peaks around River Kilometer 75 and 55. The average particulate Kepone concentration in the entire study reach is 0.00475 μg/ℓ. An average particulate Kepone concentration associated with cohesive sediment is 0.00338 μg/ℓ which is 71% of the total particulate Kepone. Organic matter has 0.00137 μg/ℓ of Kepone which is 29% of the particulate Kepone. Kepone adsorbed by the sand has its concentration of 0.000002 μg/ℓ and is an insignificant amount. As shown here, the suspended silt and clay carry the greatest amount of particulate Kepone because of their high sediment concentration. However, Figure M.49 also reveals that organic matter carries as much or more Kepone than cohesive sediment does in the region between River Kilometer 70 and 75.

Longitudinal variations of dissolved, particulate and total (sum of dissolved and particulate Kepone) Kepone concentrations at three tidal stages are shown in Figures M.50 through M.52, while tidal averaged values of these concentrations are shown in Figure M.53. As illustrated by these figures, total Kepone concentration varies from 0.0062 μg/ℓ to 0.0170 μg/ℓ with two peaks at River Kilometer 75 (near Swann Point) and River Kilometer 53 (around the null zone for this net fresh-water discharge case). Figure M.53 reveals that concentrations of dissolved, particulate and total Kepone averaged over the study area are 0.006 μg/ℓ, 0.0048 μg/ℓ and 0.0108 μg/ℓ. This implies that approximately 44% is carried by the sediment, while 56% of Kepone is in a dissolved form. As compared to Case 1 (net fresh-water discharge of 58.3 m^3/sec), the percentage of particulate Kepone to the total Kepone increases from 37 to 44%. This increase is attributed to more scouring of contaminated bed sediment and higher sediment concentrations in this case, as compared to Case 1. At River Kilometer 77, both particulate and dissolved Kepone constitute 50% of the total Kepone at maximum ebb. At slack tide 44% of the total Kepone is transported by sediment, while 56% is in a dissolved form. At maximum flood tide, 59% of Kepone is associated with sediment and 41% is in a dissolved mode. When they are tidally averaged, total Kepone concentration is 0.0140 μg/ℓof which 50.5% is in a particulate form and 49.5% has a dissolved form at River Kilometer 77.

The present mathematical study also indicates that at Burwell Bay, the tidal averaged total Kepone concentration is 0.0080 μg/ℓ and that approximately 62.3 kg of Kepone per year is discharged out from the tidal James River towards Chesapeake Bay. Dissolved and particulate Kepone concentrations are estimated to be 0.0064 μg/ℓ and 0.0016 μg/ℓ. These values imply that out of 62.3 kg of total Kepone, 12.5 kg of Kepone is transported by sediment and 49.8 kg of Kepone is in a dissolved form.

Accumulated bed elevation changes due to sediment deposition and river bed scouring after 1-month simulation are shown in Figure M.54. As shown in this figure, bays in general have sediment deposition and narrow connecting channels between bays experience bed scouring.

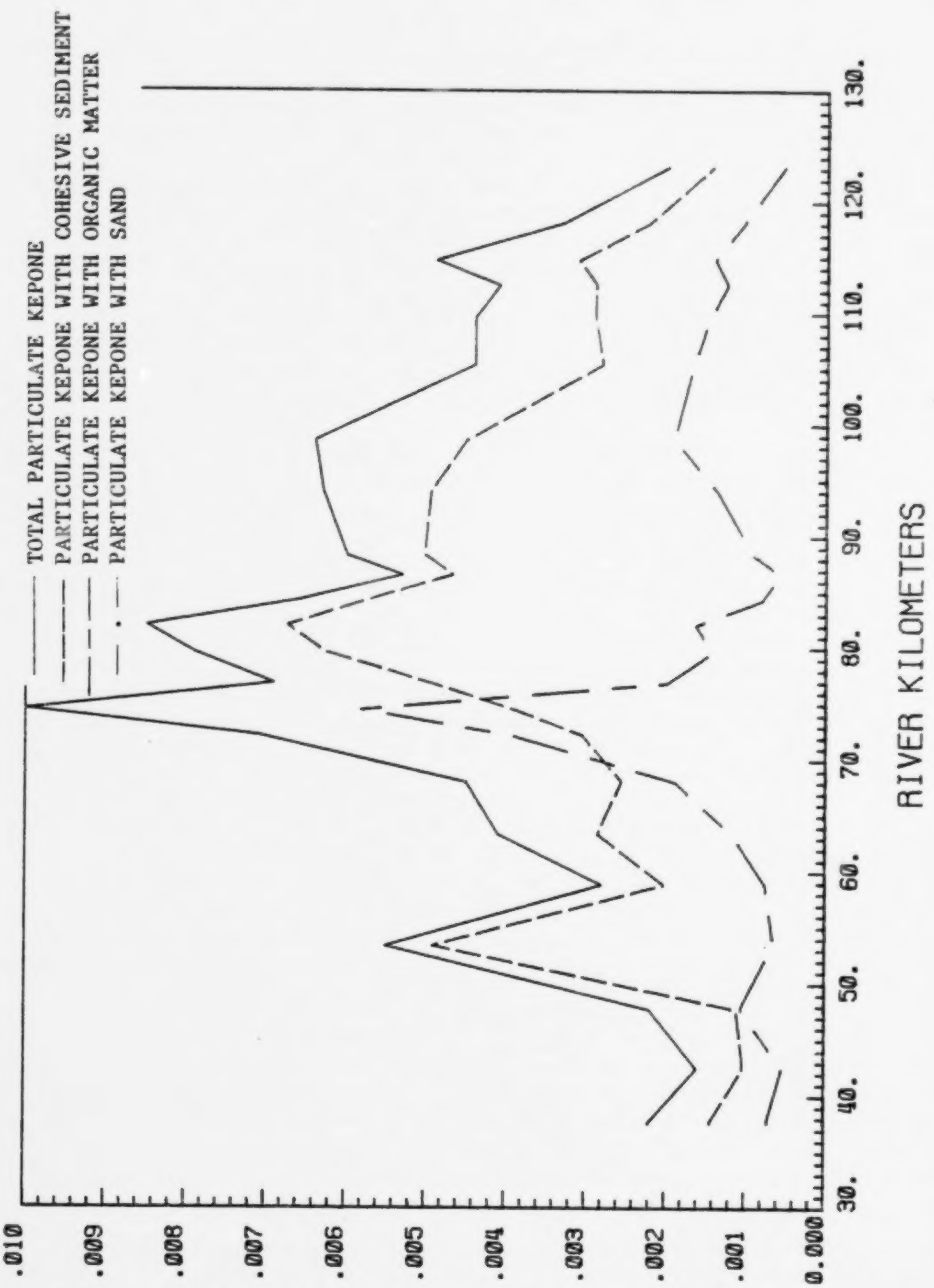

FIGURE M.46. Longitudinal Distributions of Particulate Kepone Concentrations per Unit Volume of Water at Maximum Ebb Tide for the Fresh-water Discharge of 247 m^3/sec

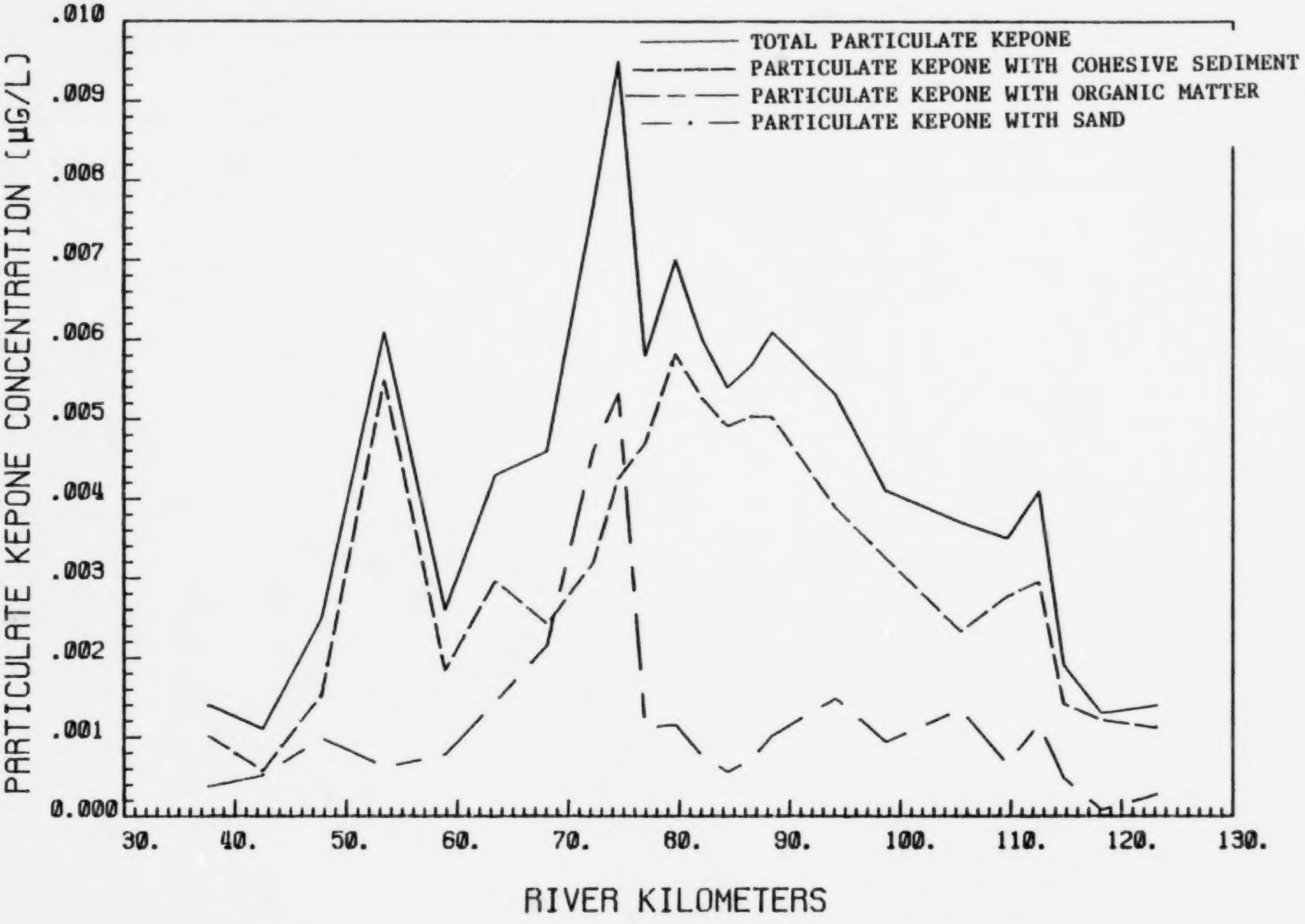

FIGURE M.47. Longitudinal Distributions of Particulate Kepone Concentrations per Unit Volume of Water at Slack Tide for the Fresh-water Discharge of 247 m^3/sec

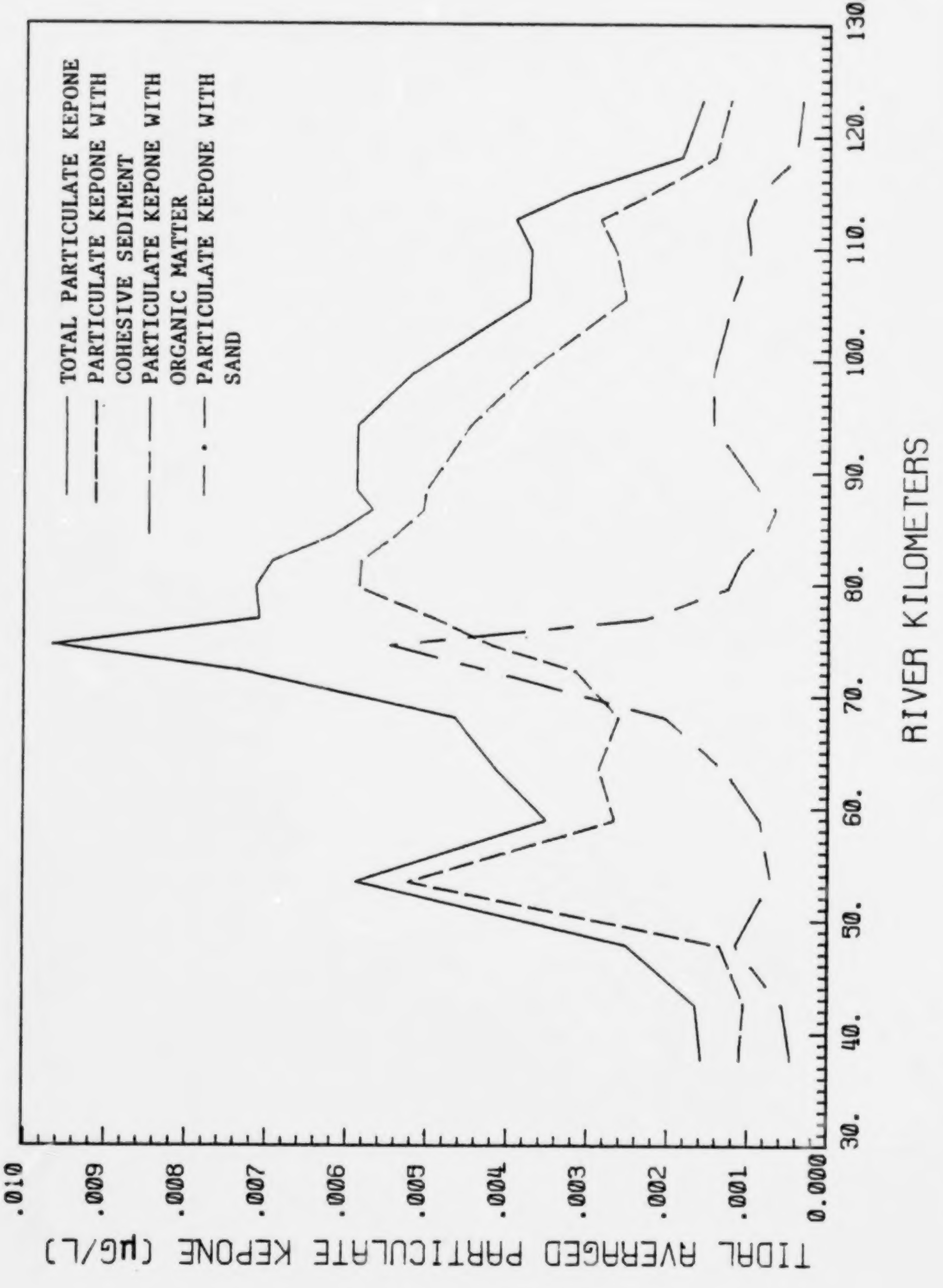

FIGURE M.48. Longitudinal Distributions of Particulate Kepone Concentrations per Unit Volume of Water at Maximum Flood Tide for the Fresh-water Discharge of 247 m^3/sec

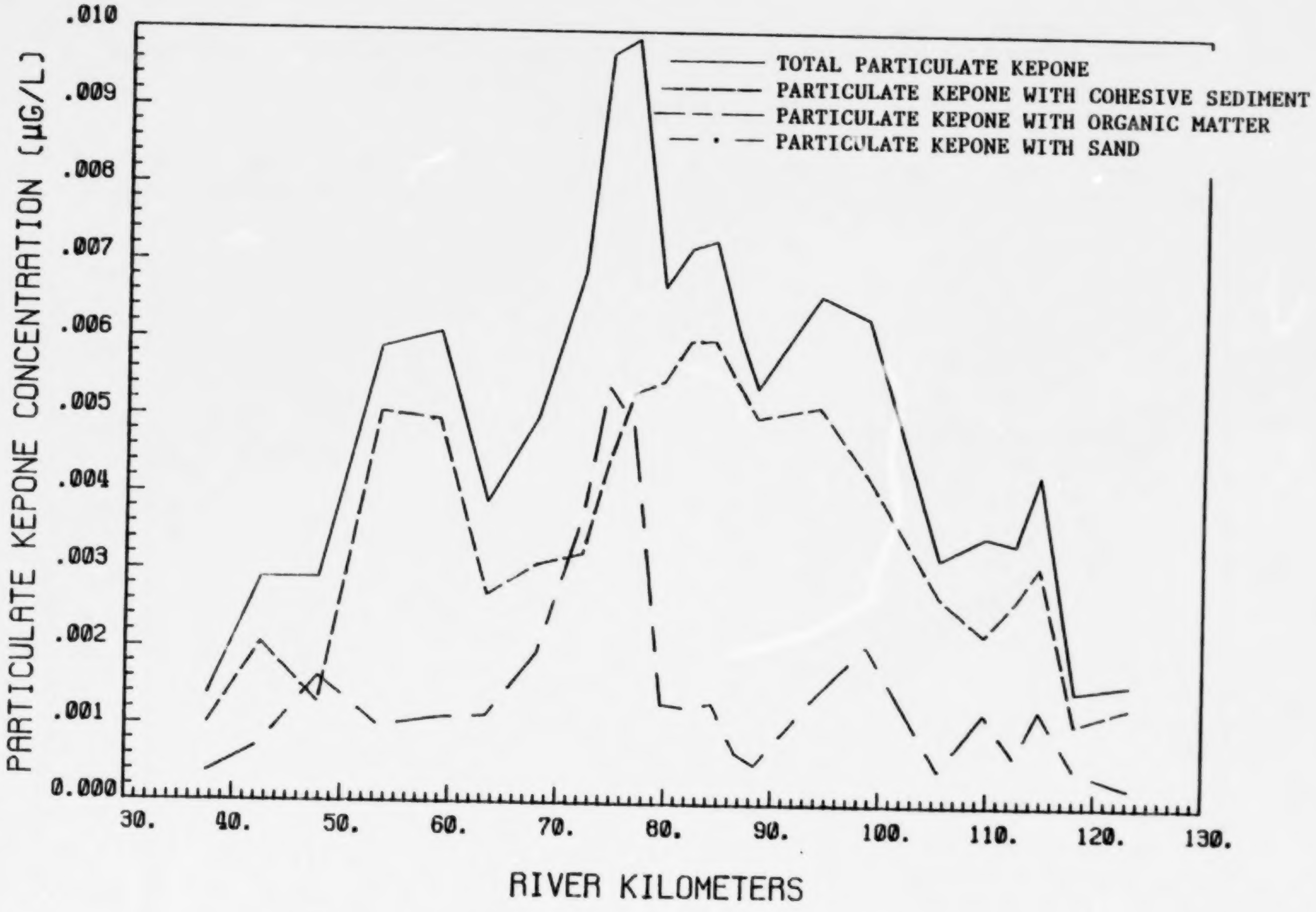

FIGURE M.49. Longitudinal Distributions of Tidal Averaged Particulate Kepone Concentrations per Unit Volume of Water for the Fresh-water Discharge of 247 m^3/sec

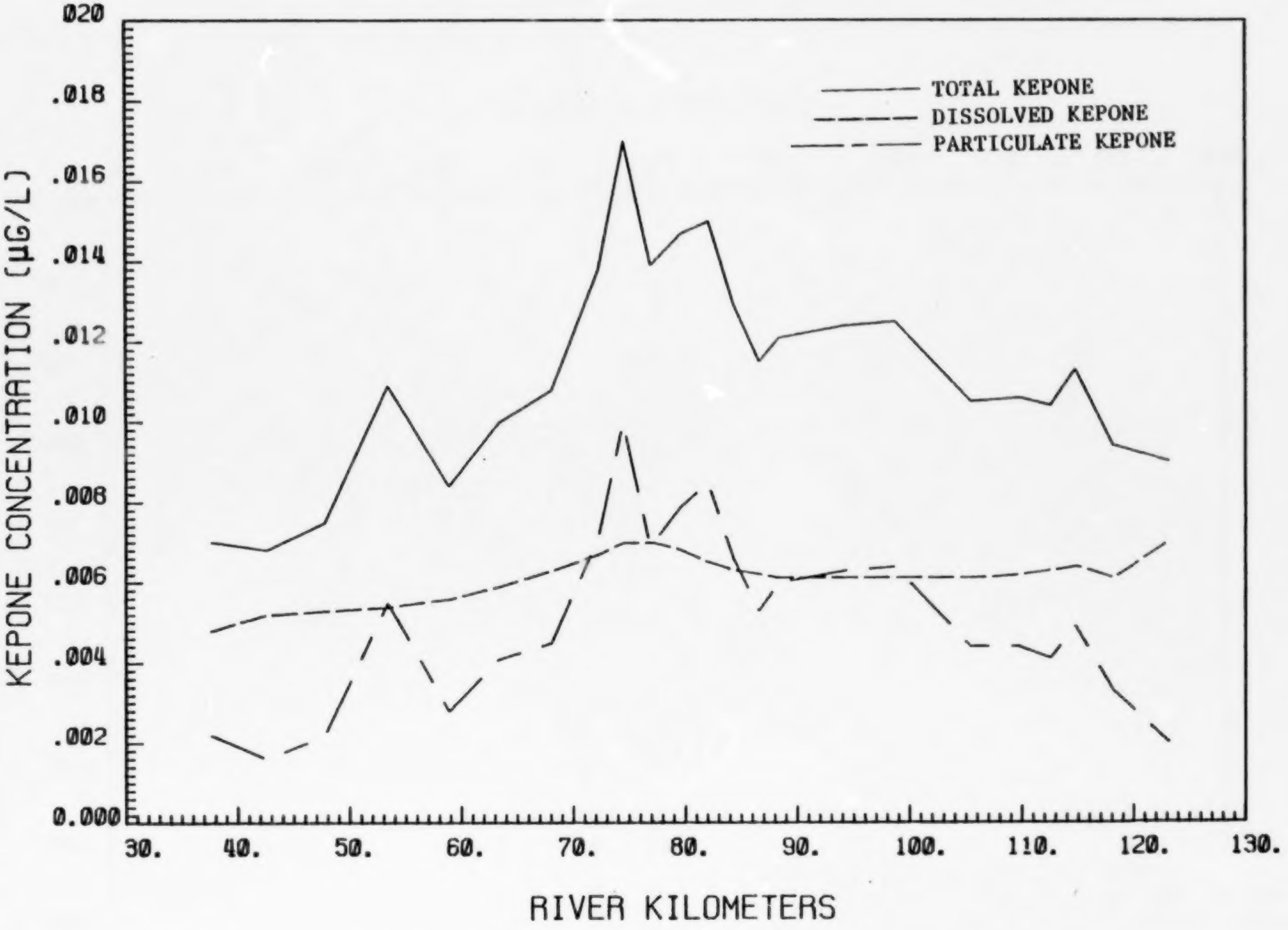

FIGURE M.50. Longitudinal Distributions of Total, Dissolved and Particulate Kepone Concentrations at Maximum Ebb Tide for the Fresh-water Discharge of 247 m^3/sec

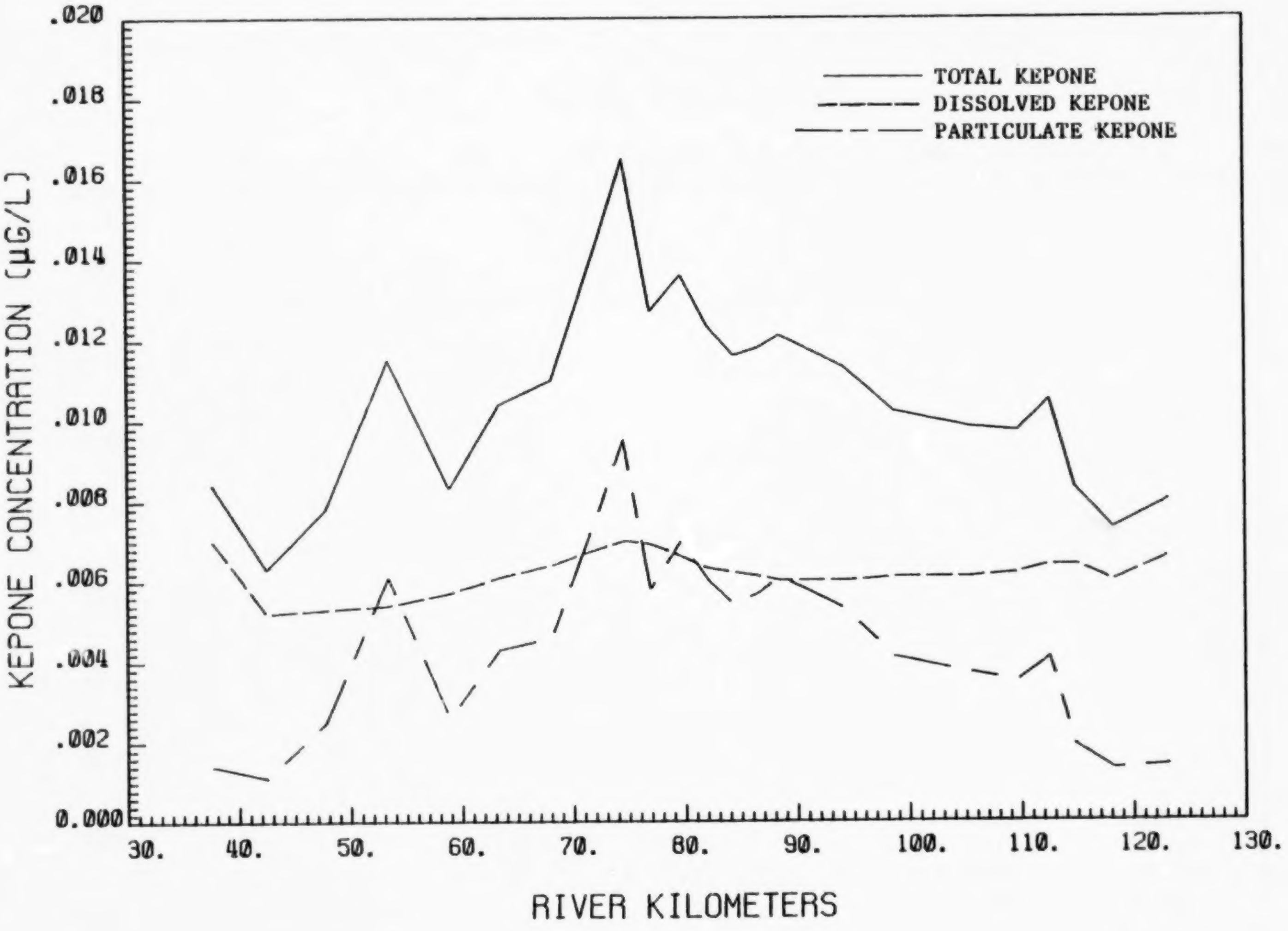

FIGURE M.51. Longitudinal Distributions of Total, Dissolved and Particulate Kepone Concentrations at Slack Tide for the Fresh-water Discharge of 247 m^3/sec

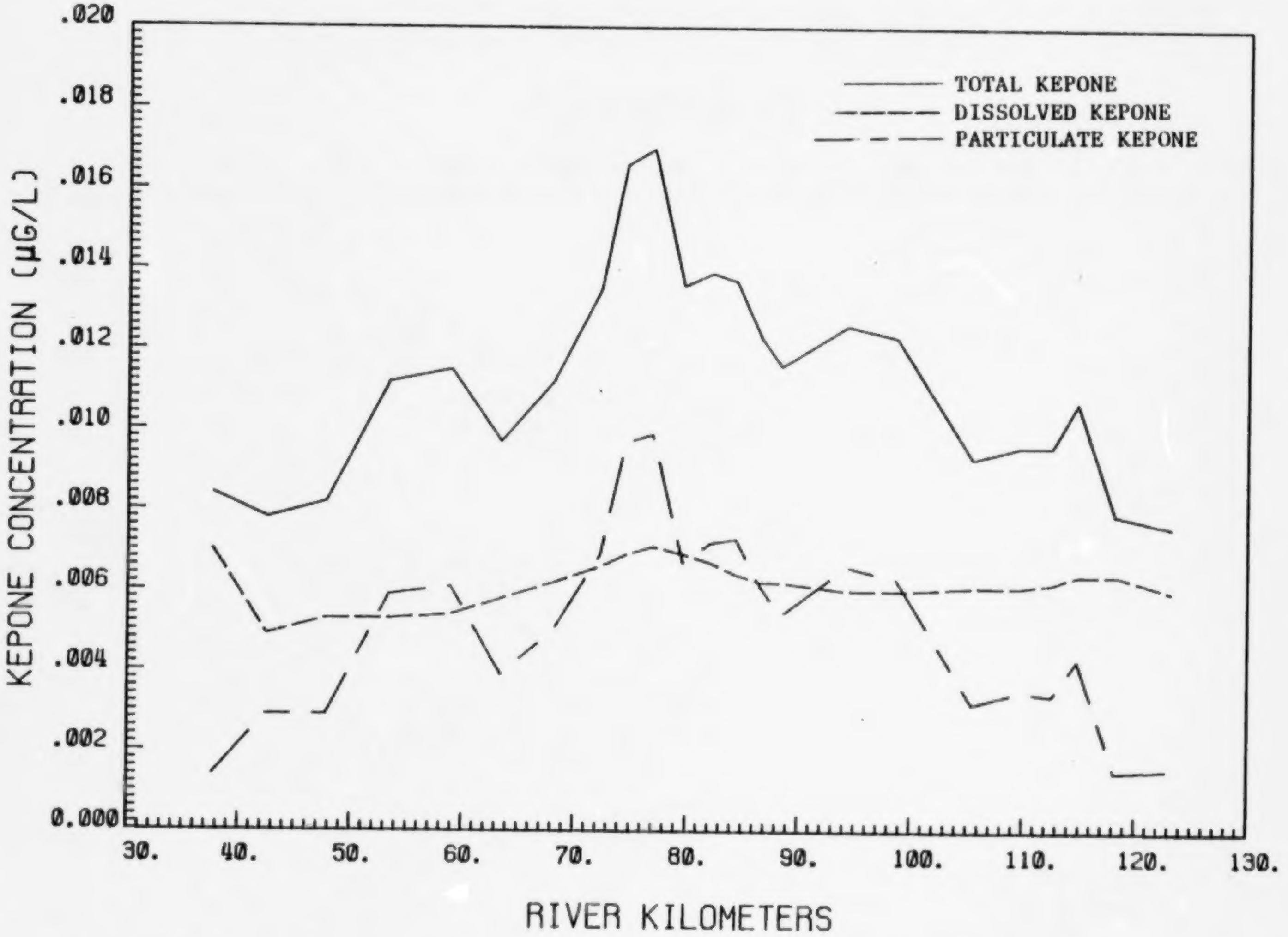

FIGURE M.52. Longitudinal Distributions of Total, Dissolved and Particulate Kepone Concentrations at Maximum Flood Tide for the Fresh-water Discharge of 247 m^3/sec

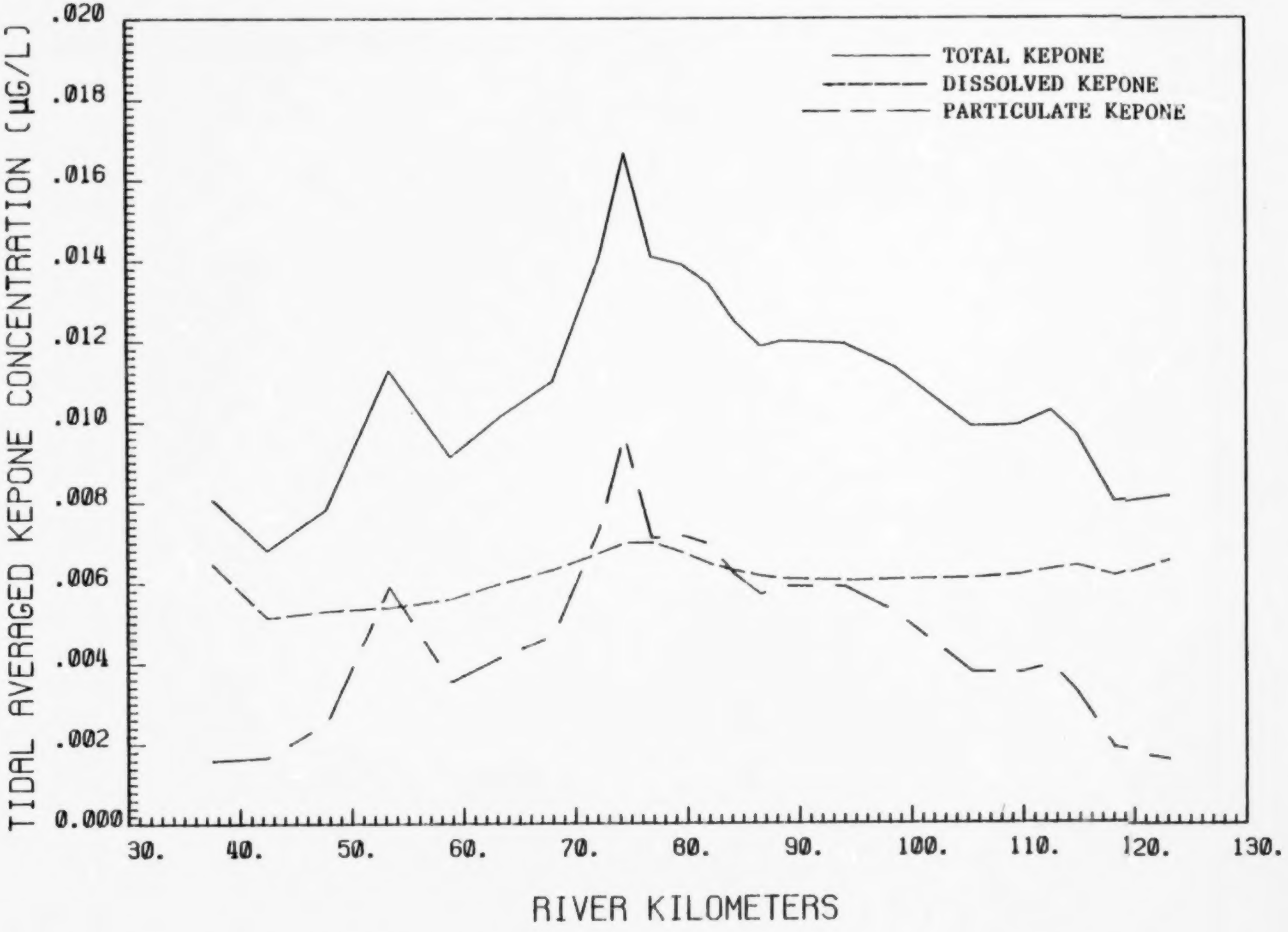

FIGURE M.53. Longitudinal Distributions of Tidal Averaged Total, Dissolved and Particulate Kepone Concentrations for the Fresh-water Discharge of 247 m^3/sec

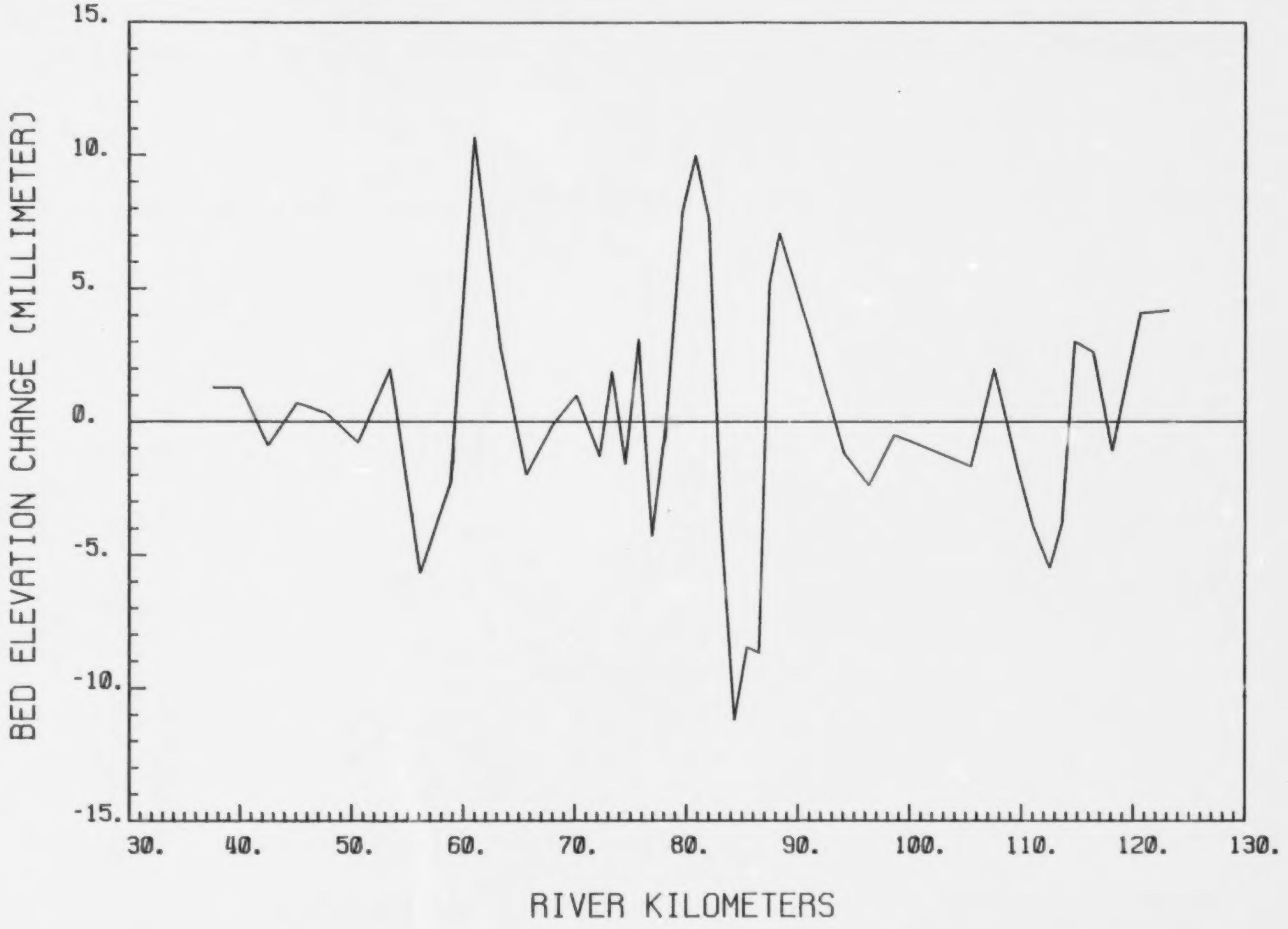

FIGURE M.54. Variation of River Bed Elevation Changes Due to Sediment Deposition and/or Bed Scouring at Maximum Ebb Tide for the Fresh-water Discharge of 247 m^3/sec

For this case an average annual net bed deposition rate for the 86-km tidal James River reach is predicted to be approximately 3.6 mm/yr. Figure M.55 indicates the change in bed surface Kepone concentration and reveals a similar trend to that found in Case 1 (Figure M.17).

Case 3 - Net Fresh-water Discharge of 681 m^3/sec

Mathematical simulation results on velocity and flow depth distributions at the three tidal stages are shown in Figures M.56 through M.59.

Figures M.60 through M.62 present concentrations of cohesive sediment, organic matter, sand and total sediment at maximum ebb, slack and maximum flood tides, respectively. Tidal averaged distributions of these concentrations are shown in Figure M.63. These figures show that total sediment concentration changes its values from approximately 20 mg/ℓ to 110 mg/ℓ with a series of peaks at River Kilometer 38, 54, 72 and 105. These figures also reveal that the majority of the sediment being transported in the river at this discharge is cohesive sediment ranging from 94 to 68% of the total sediment concentration. Organic matter constitutes 6 to 32% of the total and sand constitutes only a fraction of total sediment. As shown in Figure M.63, tidal averaged total sediment concentration over the entire 86-km reach is 74.2 mg/ℓ. Concentrations of cohesive sediment, organic matter and sand averaged over the study area are 59.7 mg/ℓ, 13.7 mg/ℓ and 0.8 mg/ℓ, respectively. This means that cohesive sediment, organic matter, and sand constitute 80.4%, 18.5% and 1.1% of the total sediment concentration, respectively. As compared to Cases 1 and 2, all components of sediment have higher concentrations than Cases 1 and 2. Moreover, organic matter and sand increase their contributions to total sediment concentrations but the cohesive sediment decreases its percentage.

Figures M.64 through M.66 present longitudinal variations of particulate Kepone concentrations at the three tidal stages, while Figure M.67 shows the tidal averaged particulate Kepone concentration. These figures indicate that total particulate Kepone changes its concentrations from 0.035 μg/g to 0.10 μg/g and has three peaks, one each at River Kilometer 43, 75, and 118. Tidal averaged total particulate Kepone over the 86-km reach, as shown in Figure M.67 is 0.076 μg/g. Particulate Kepone adsorbed by cohesive sediment, organic material and sand averaged over the entire study reach are 0.064 μg/g, 0.129 μg/g and 0.006 μg/g, respectively.

Particulate Kepone concentrations per unit volume of water, expressed by μg/ℓ are shown in Figure M.68 through M.71. Figure M.71 show that the tidal averaged total Kepone concentration for this case varies from 0.0012 μg/ℓ to 0.0084 μg/ℓ with the average value of 0.0057 μg/ℓ. Also this distribution has two major peaks and two minor peaks at River Kilometer 37, 54, 72 and 105, respectively. Concentrations of particulate Kepone attached to cohesive sediment, organic material and sand are estimated to be 0.0039 μg/ℓ, 0.0018 μg/ℓ and 0.000004 μg/ℓ, respectively. These values correspond to 68.4, 31.5, and 0.07%, respectively, to the total Kepone concentration.

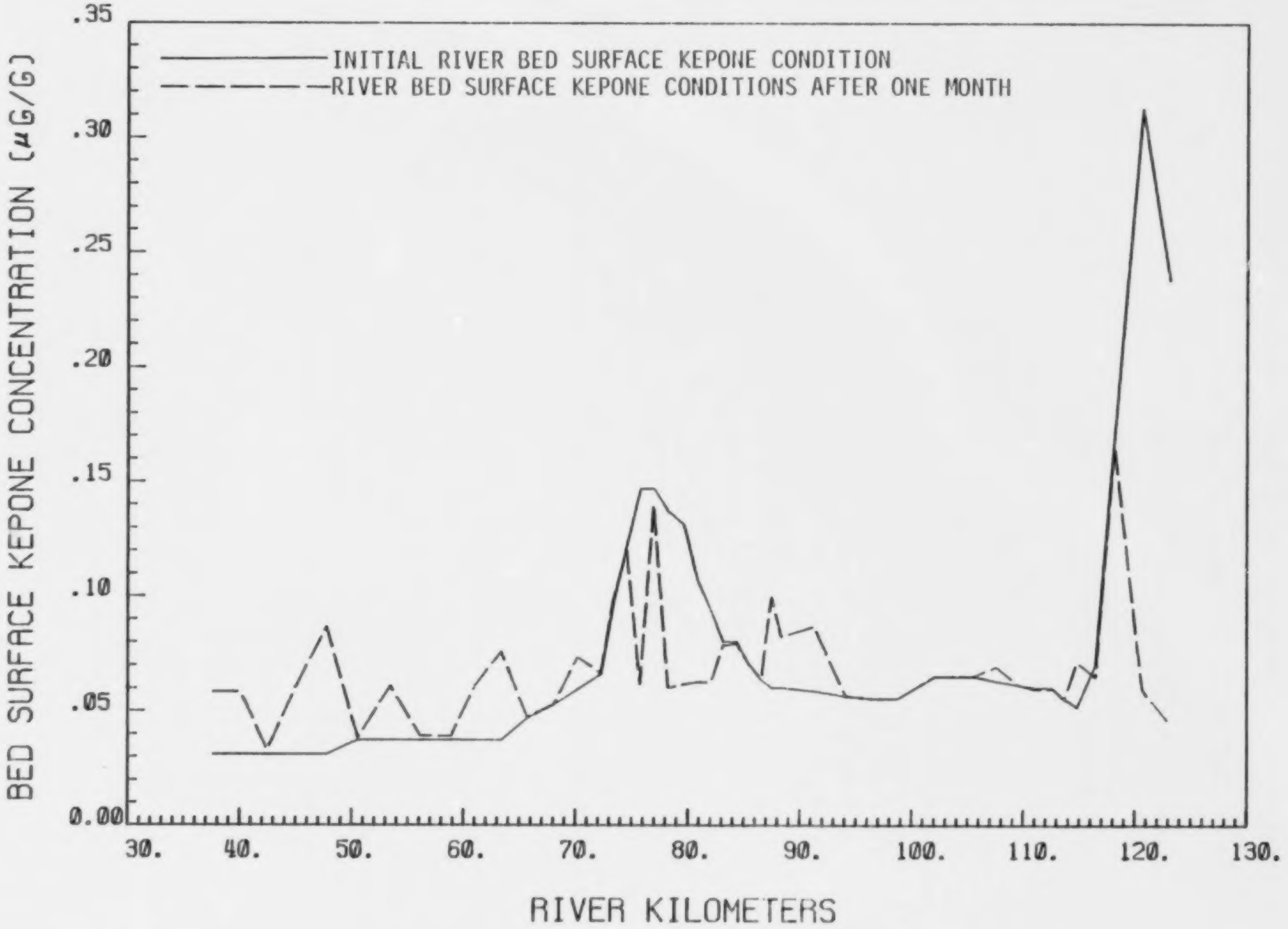

FIGURE M.55. Change in Bed Surface Kepone Concentration Occurred During 1-Month Simulation for the Fresh-water Discharge of 247 m^3/sec

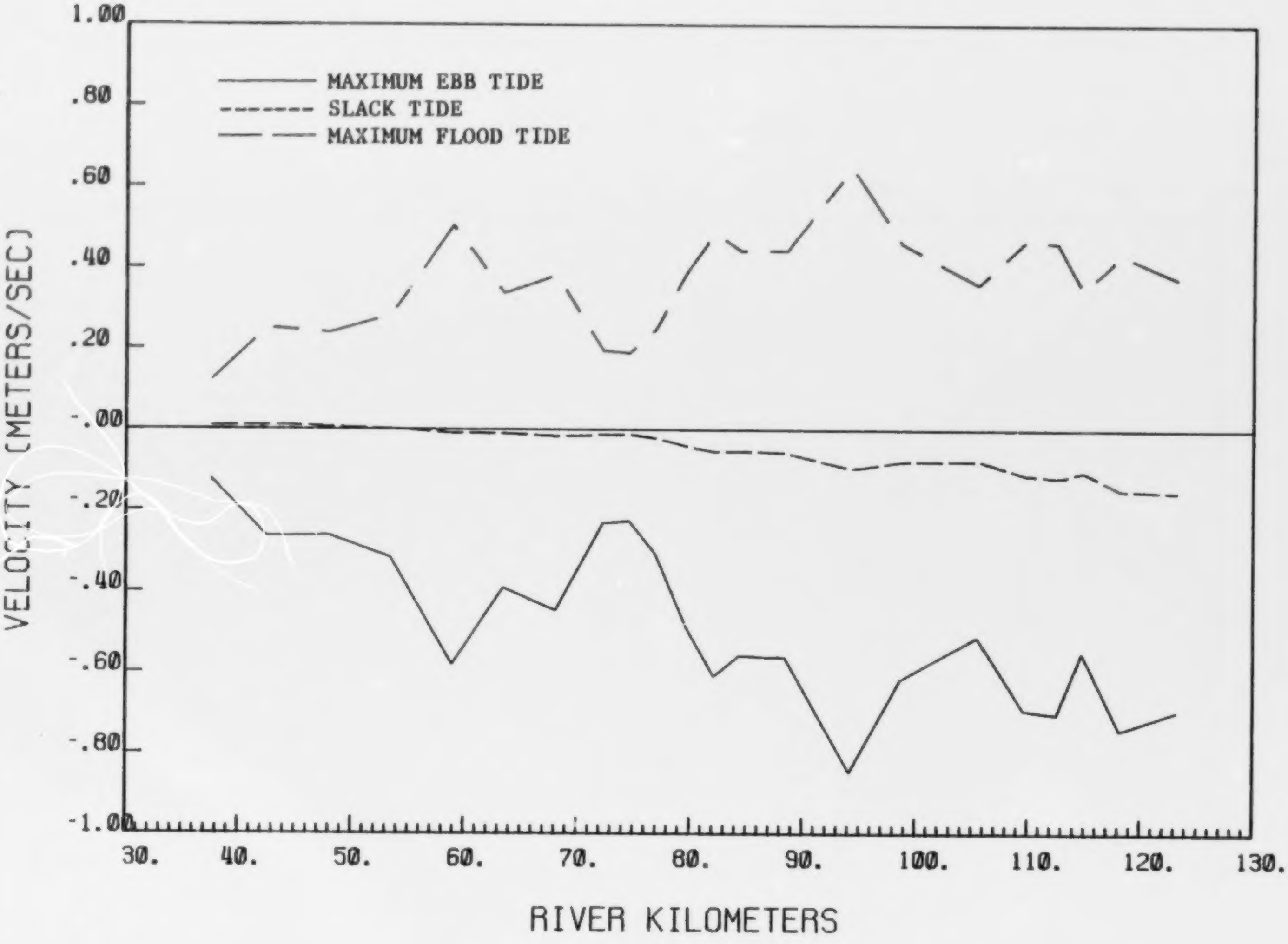

FIGURE M.56. Longitudinal Velocity Distributions at Maximum Ebb, Slack and the Maximum Flood Tides for Fresh-water Input Discharge of 681 m^3/sec

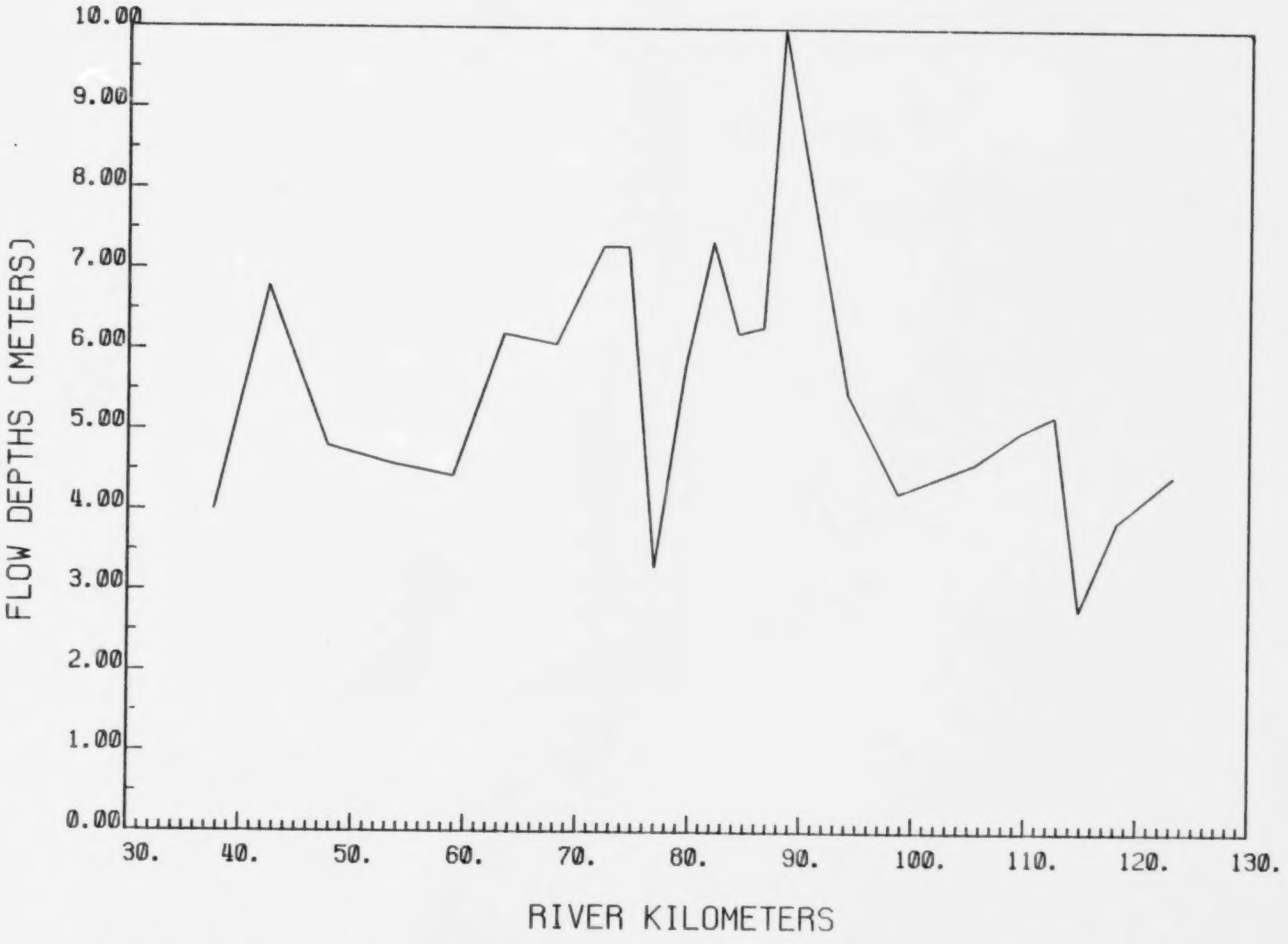

FIGURE M.57. Longitudinal Depth Variation at Maximum Ebb Tide for the Fresh-water Discharge of 681 m^3/sec

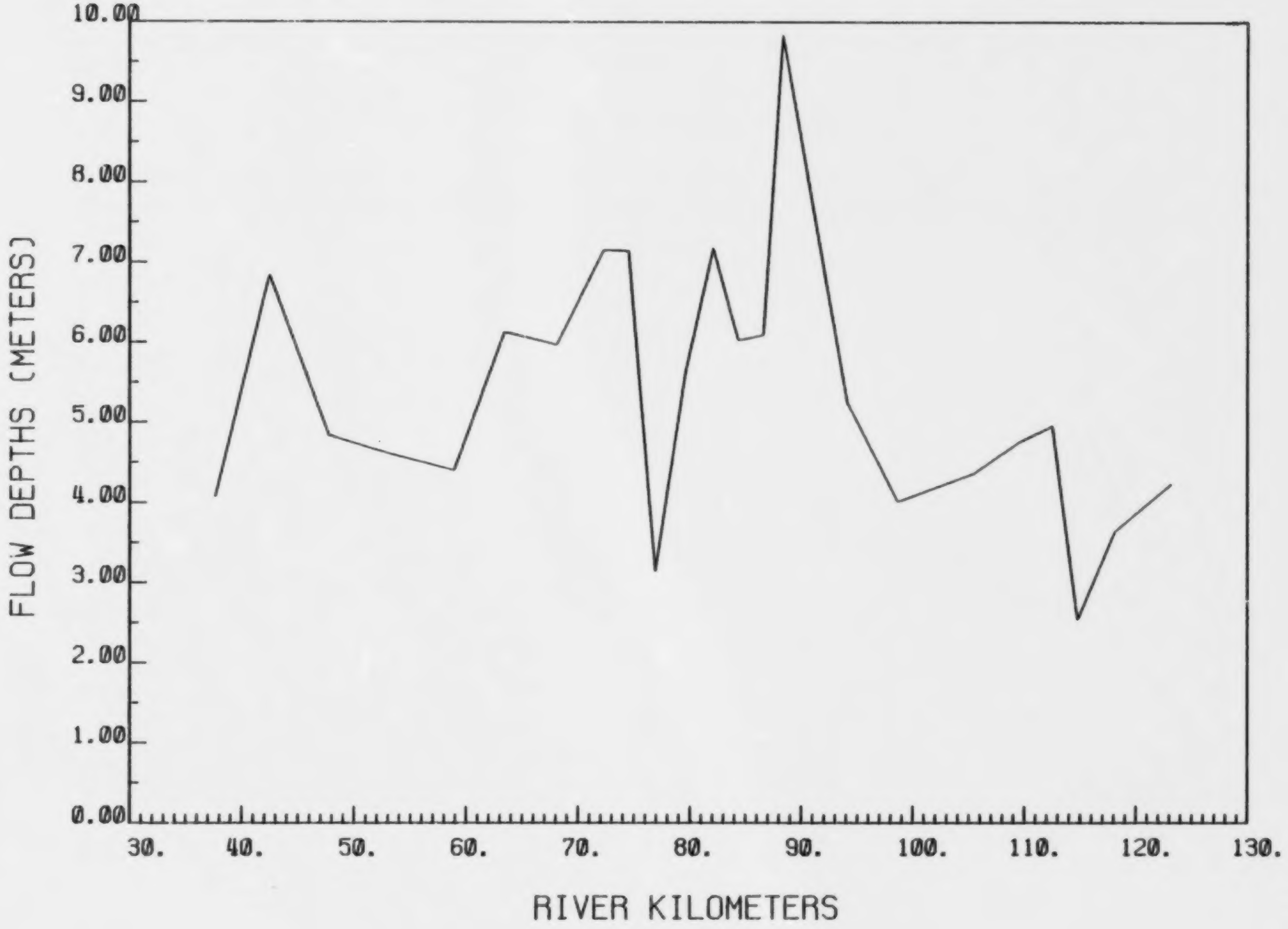

FIGURE M.58. Longitudinal Depth Variation at Slack Tide for the Fresh-water Discharge of 58.3 m^3/sec

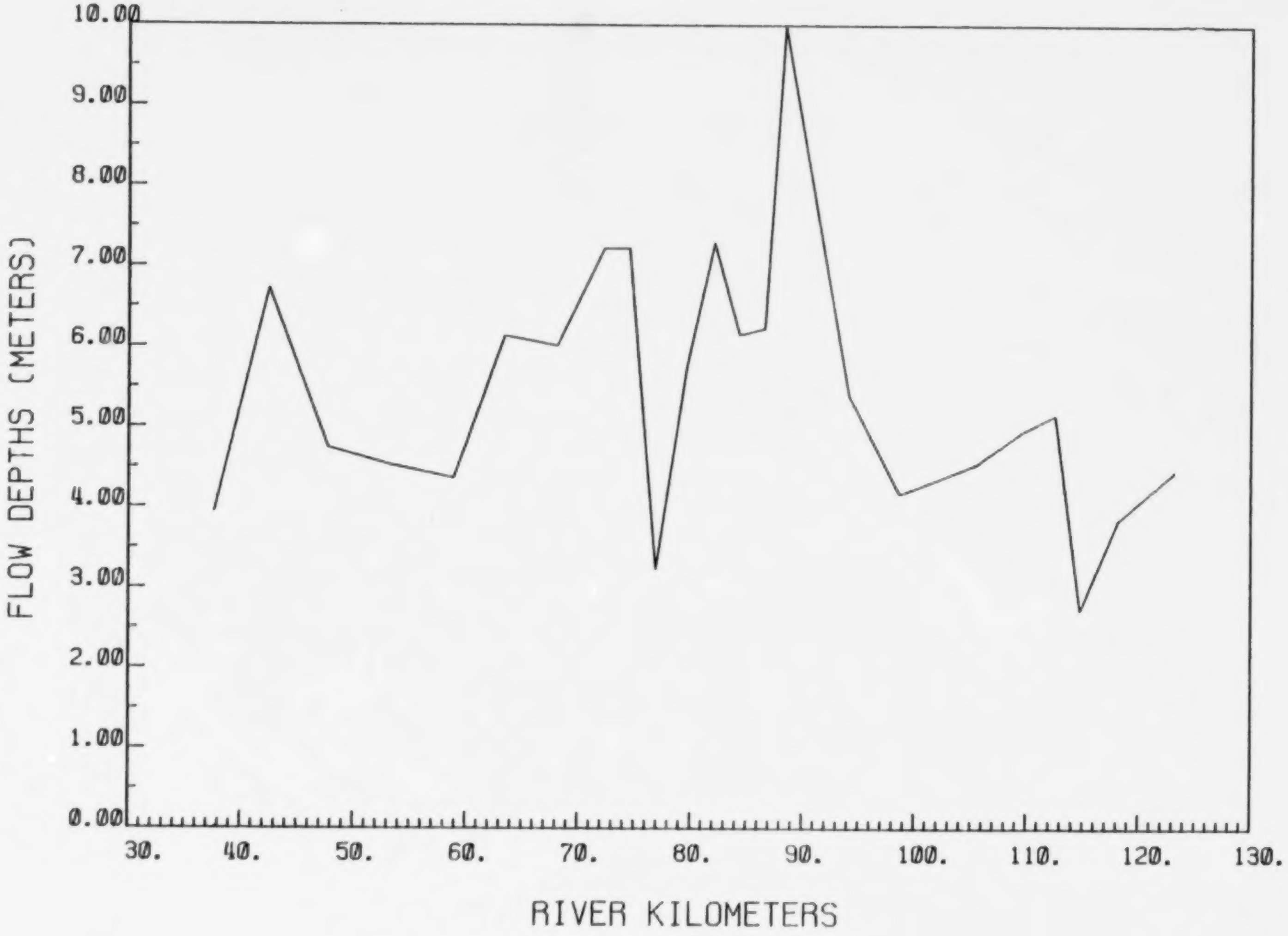

FIGURE M.59. Longitudinal Depth Variations at Maximum Flood Tide for the Fresh-water Discharge of 681 m^3/sec

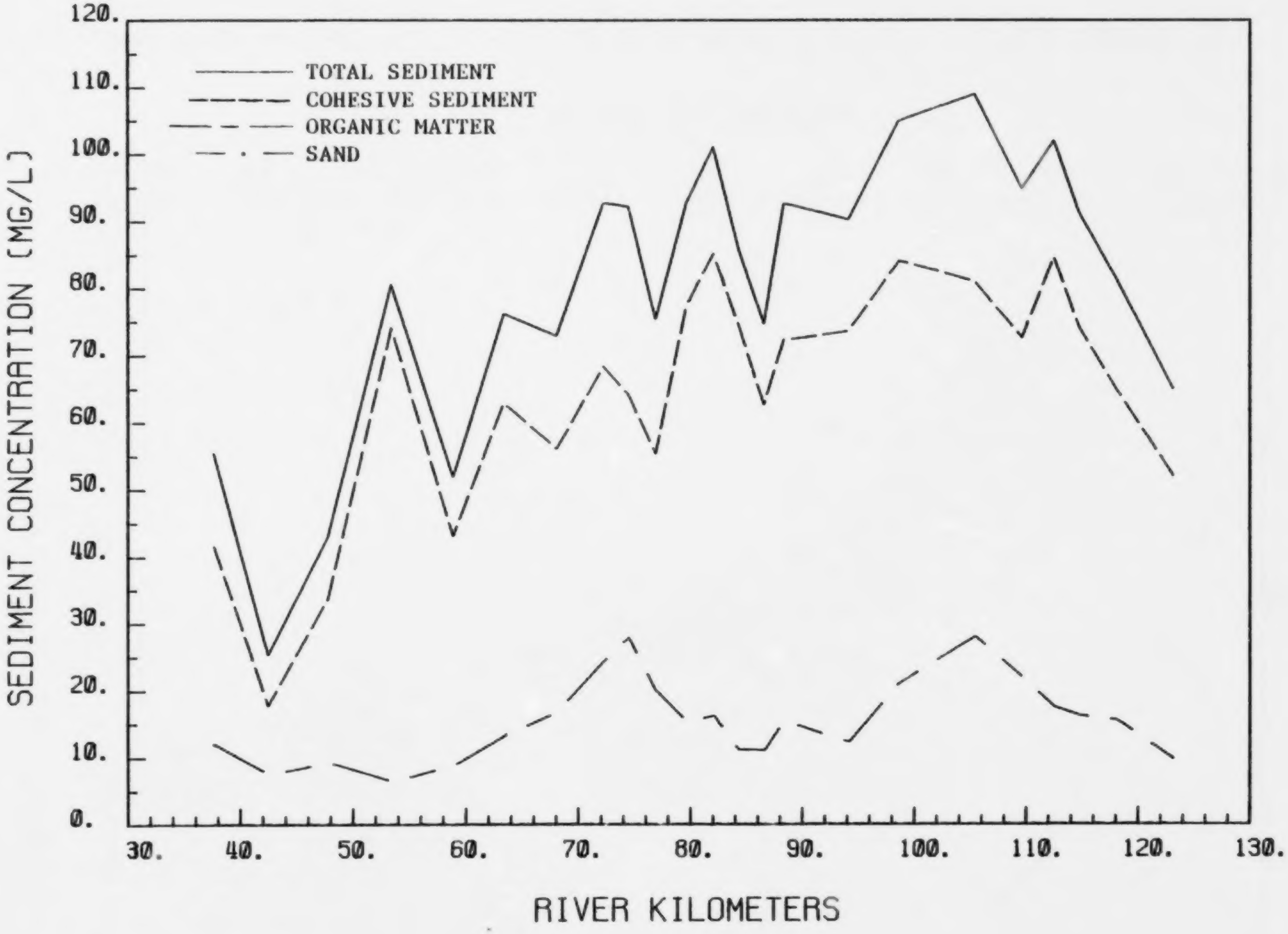

FIGURE M.60. Longitudinal Distribution of Sediment Concentration of Each Sediment Type at Maximum Ebb Tide for the Fresh-water Discharge of 681 m^3/sec

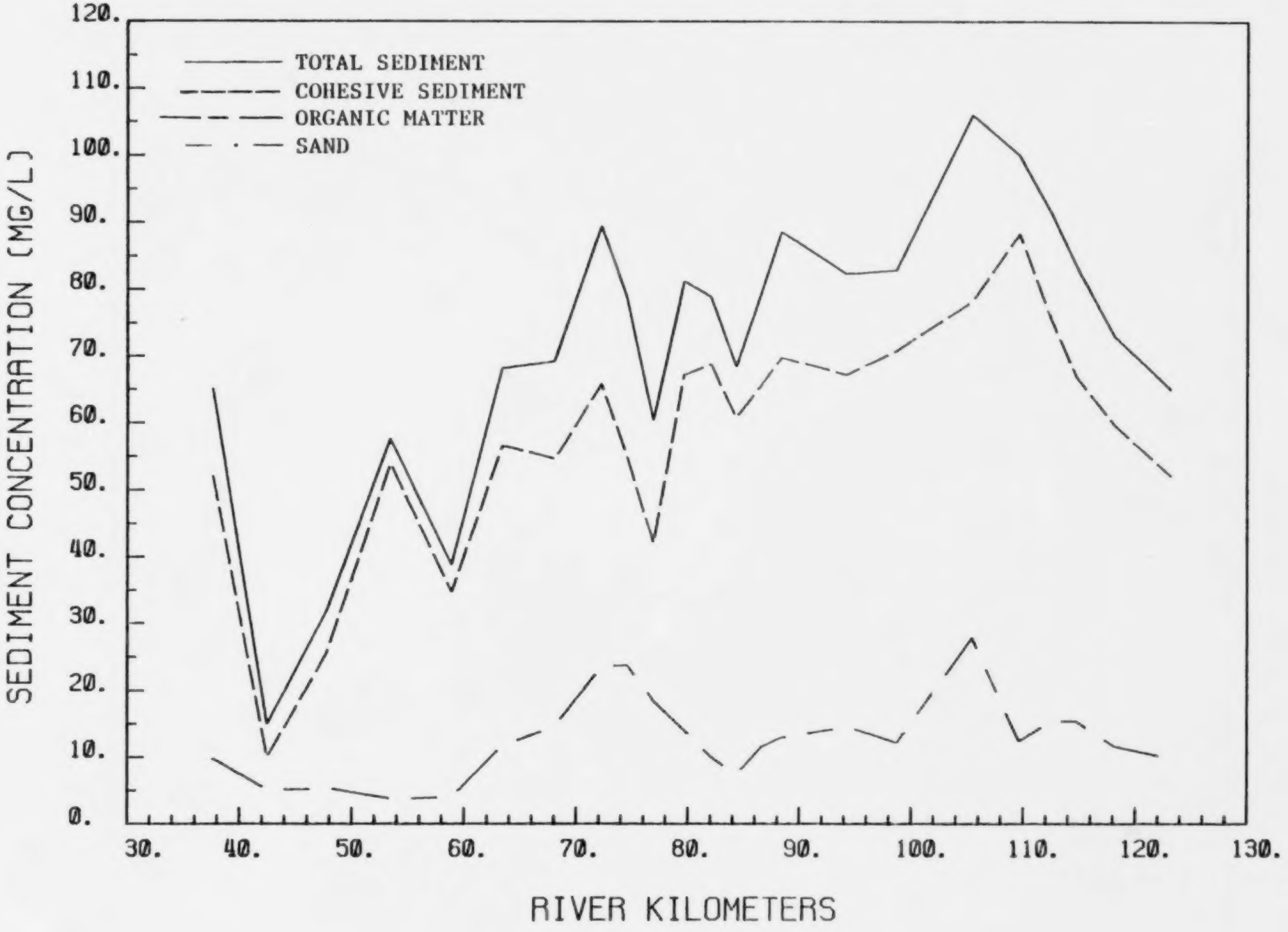

FIGURE M.61. Longitudinal Distribution of Sediment Concentration of Each Sediment Type at Slack Tide for the Fresh-water Discharge of 681 m^3/sec

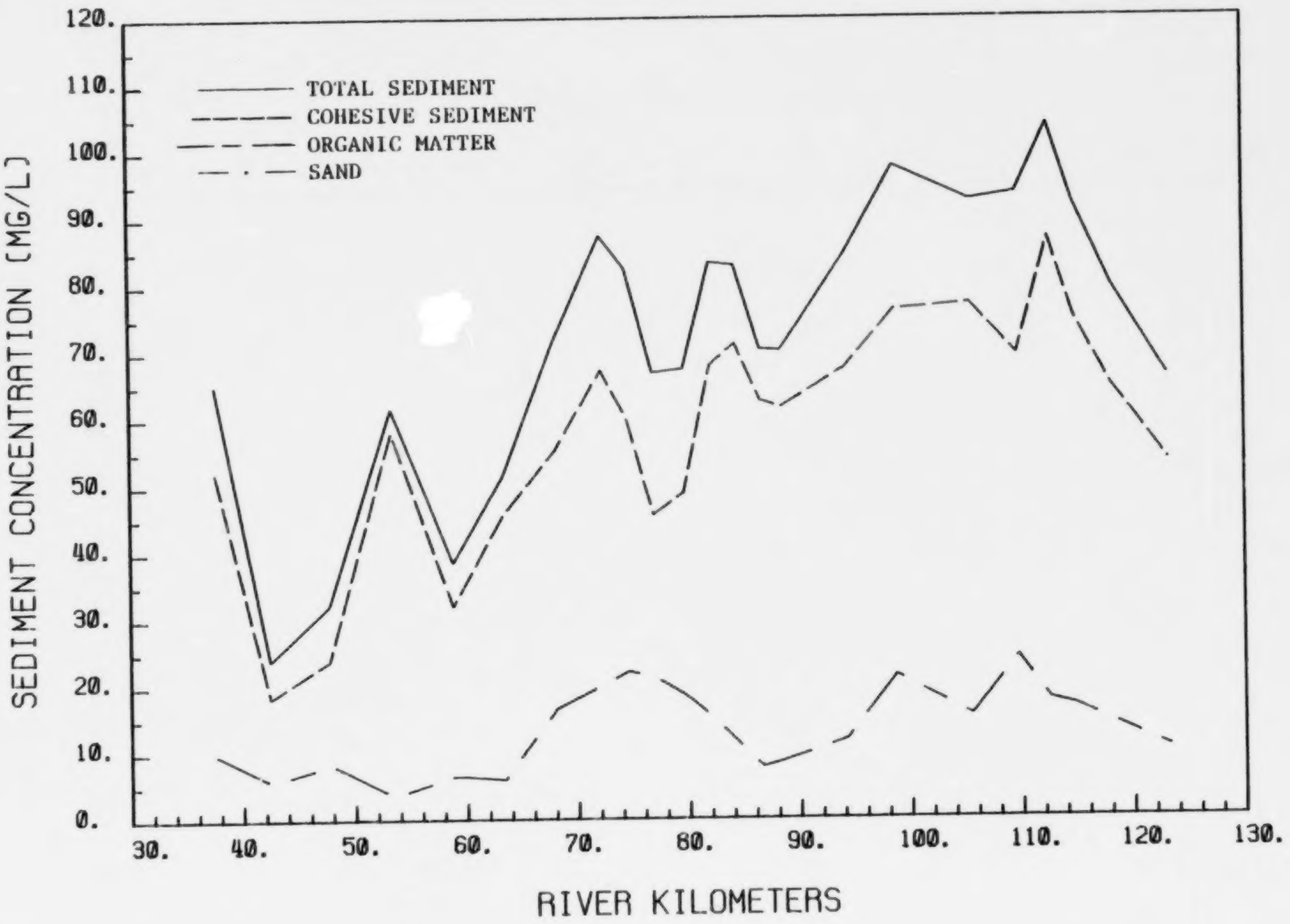

FIGURE M.62. Longitudinal Distributions of Sediment Concentration of Each Sediment Type at Maximum Flood Tide for the Fresh-water Discharge of 681 m^3/sec

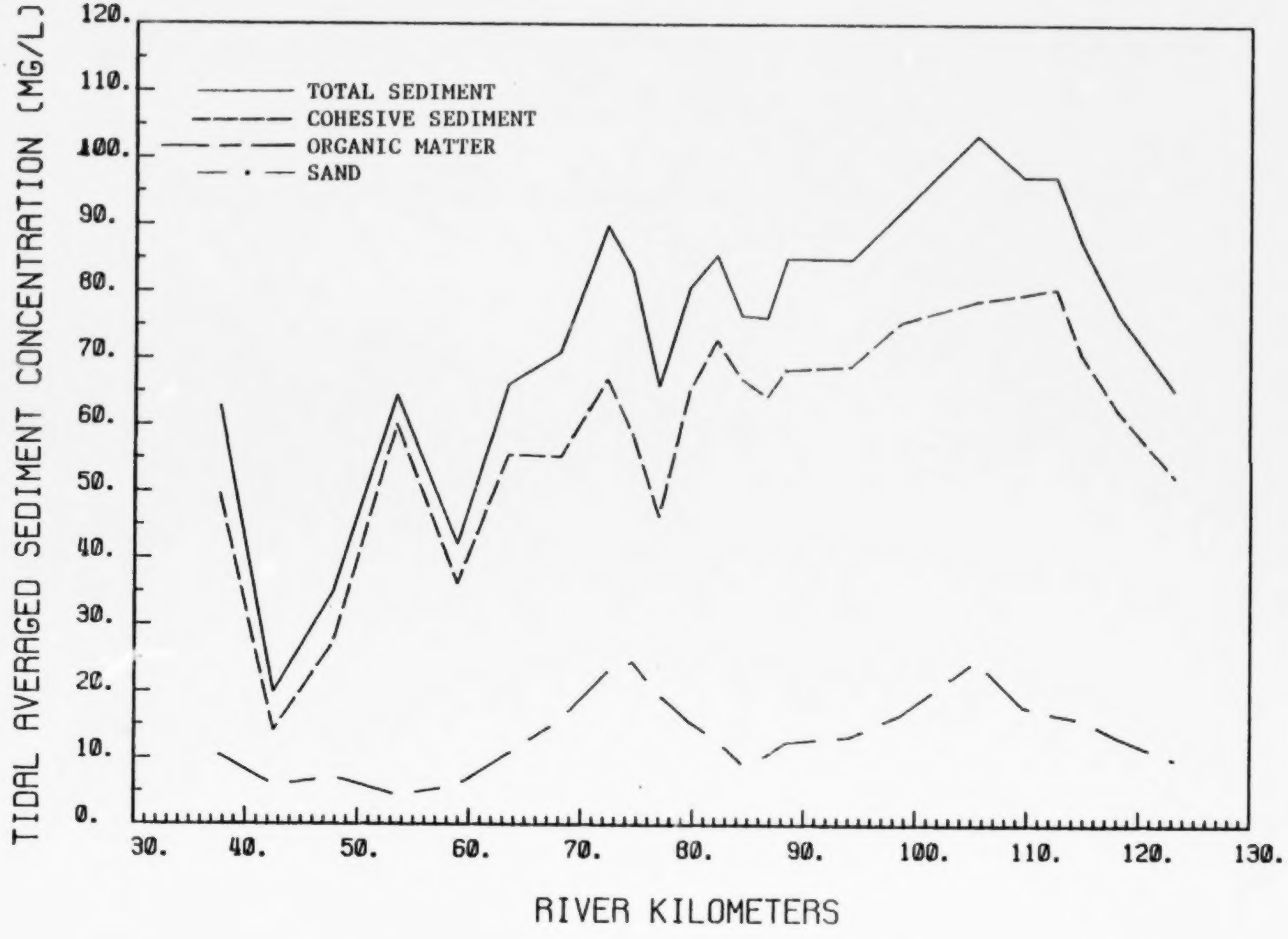

FIGURE M.63. Tidal Averaged Sediment Concentration of Each Sediment Type for the Fresh-water Discharge of 681 m^3/sec

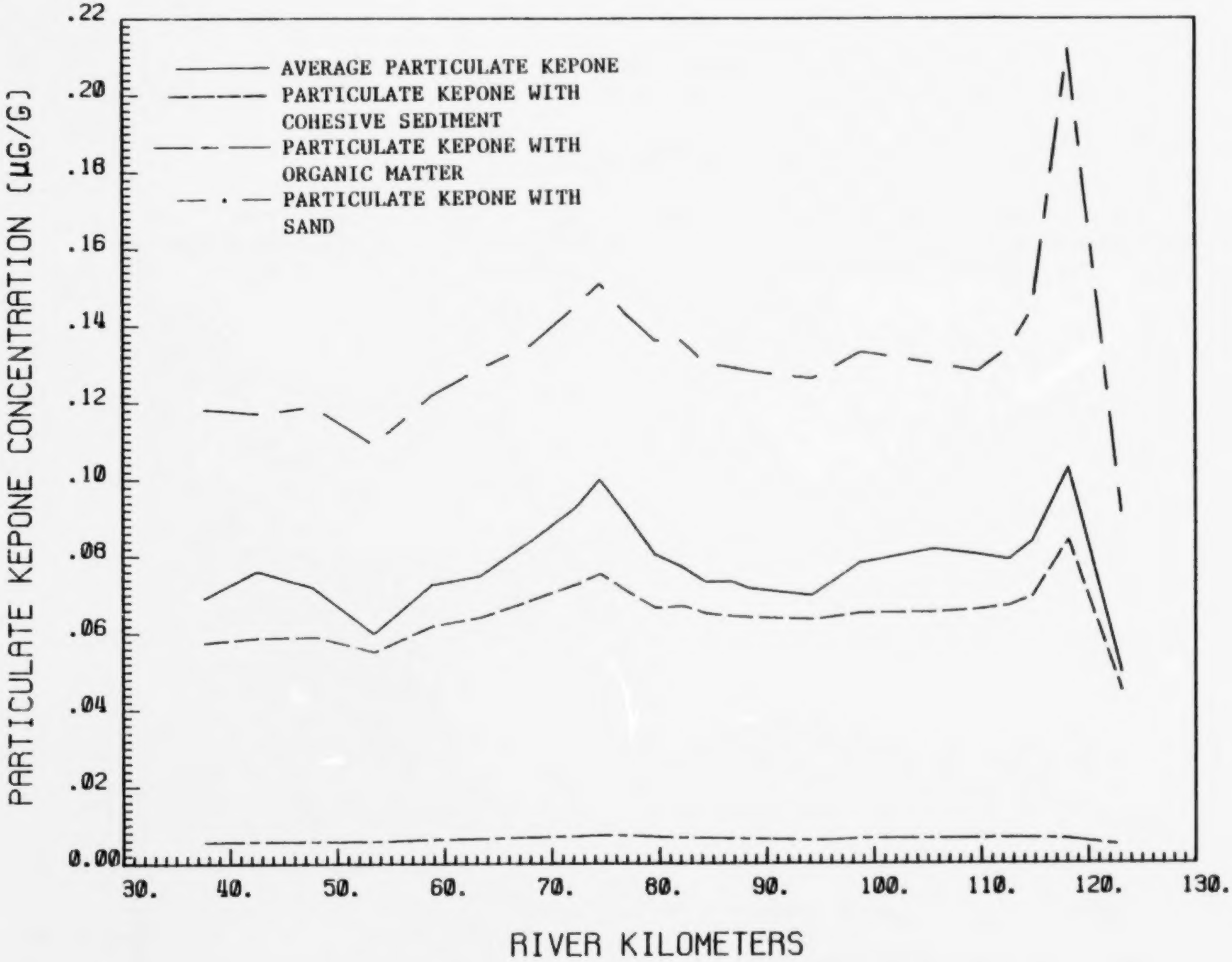

FIGURE M.64. Longitudinal Distributions of Particulate Kepone Concentrations at Maximum Ebb Tide for the Fresh-water Discharge to 681 m^3/sec

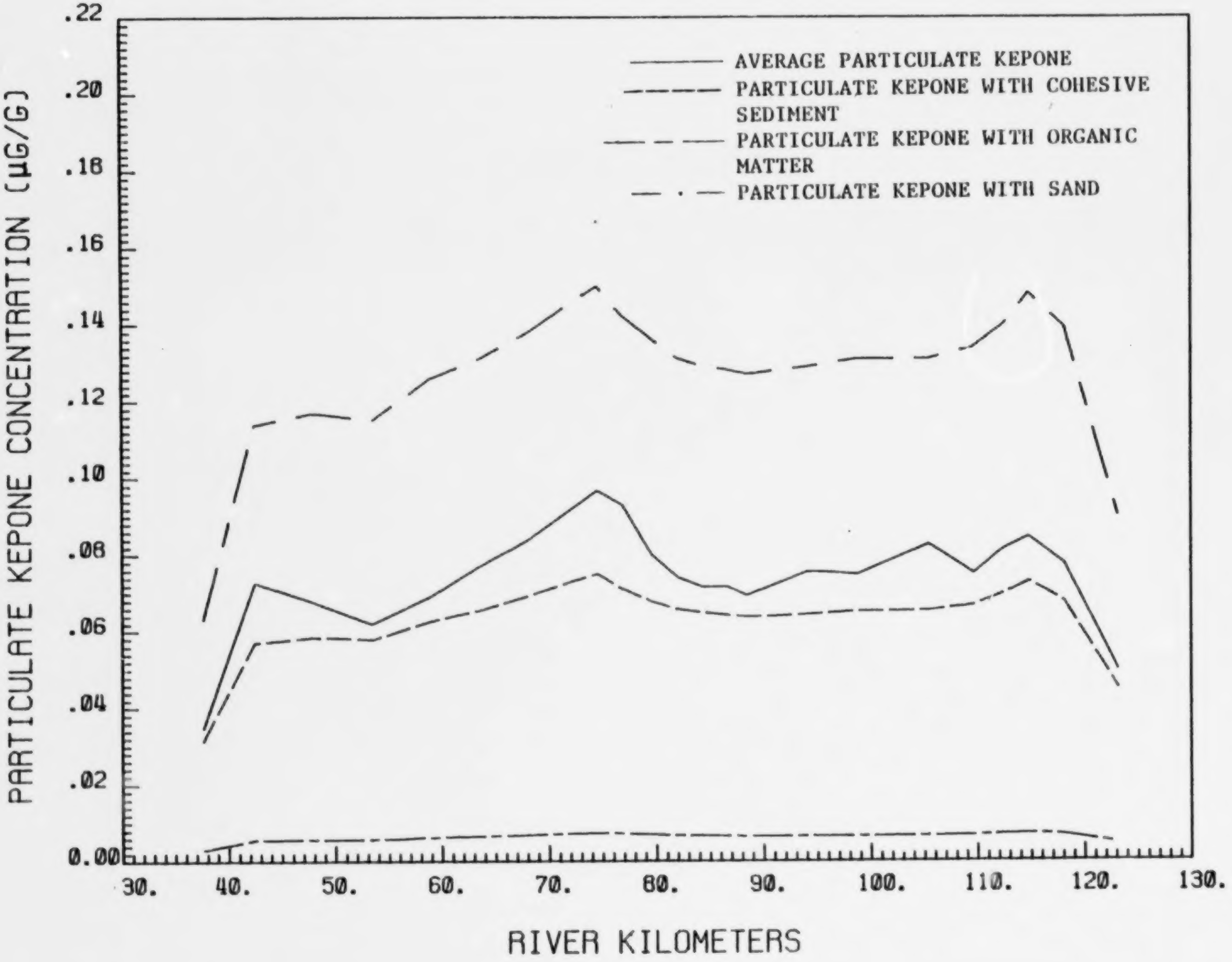

FIGURE M.65. Longitudinal Distributions of Particulate Kepone Concentrations at Slack Tide for the Fresh-water Discharges of 681 m^3/sec

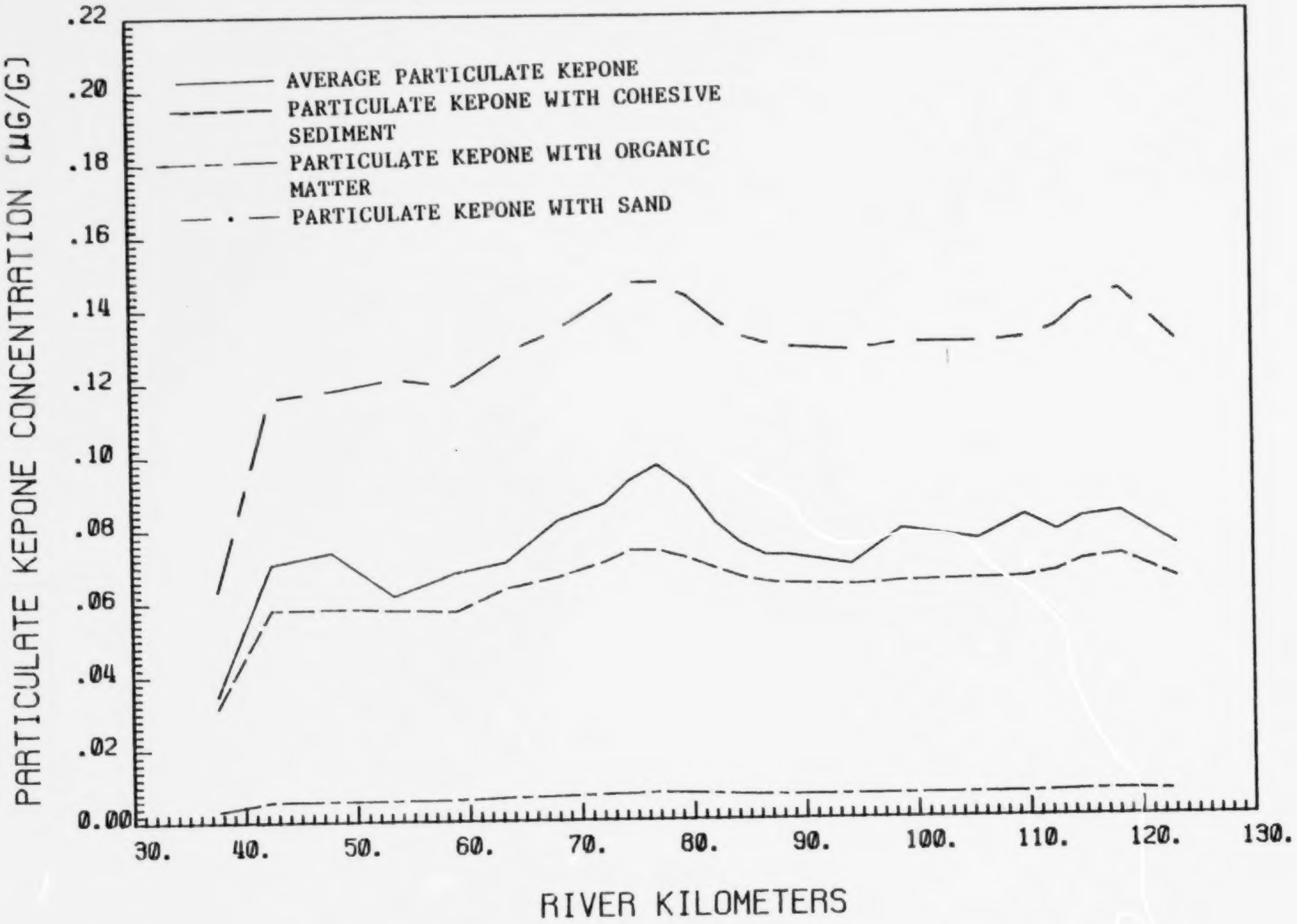

FIGURE M.66. Longitudinal Distributions of Particulate Kepone Concentrations at Maximum Flood Tide for the Fresh-water Discharge of 681 m^3/sec

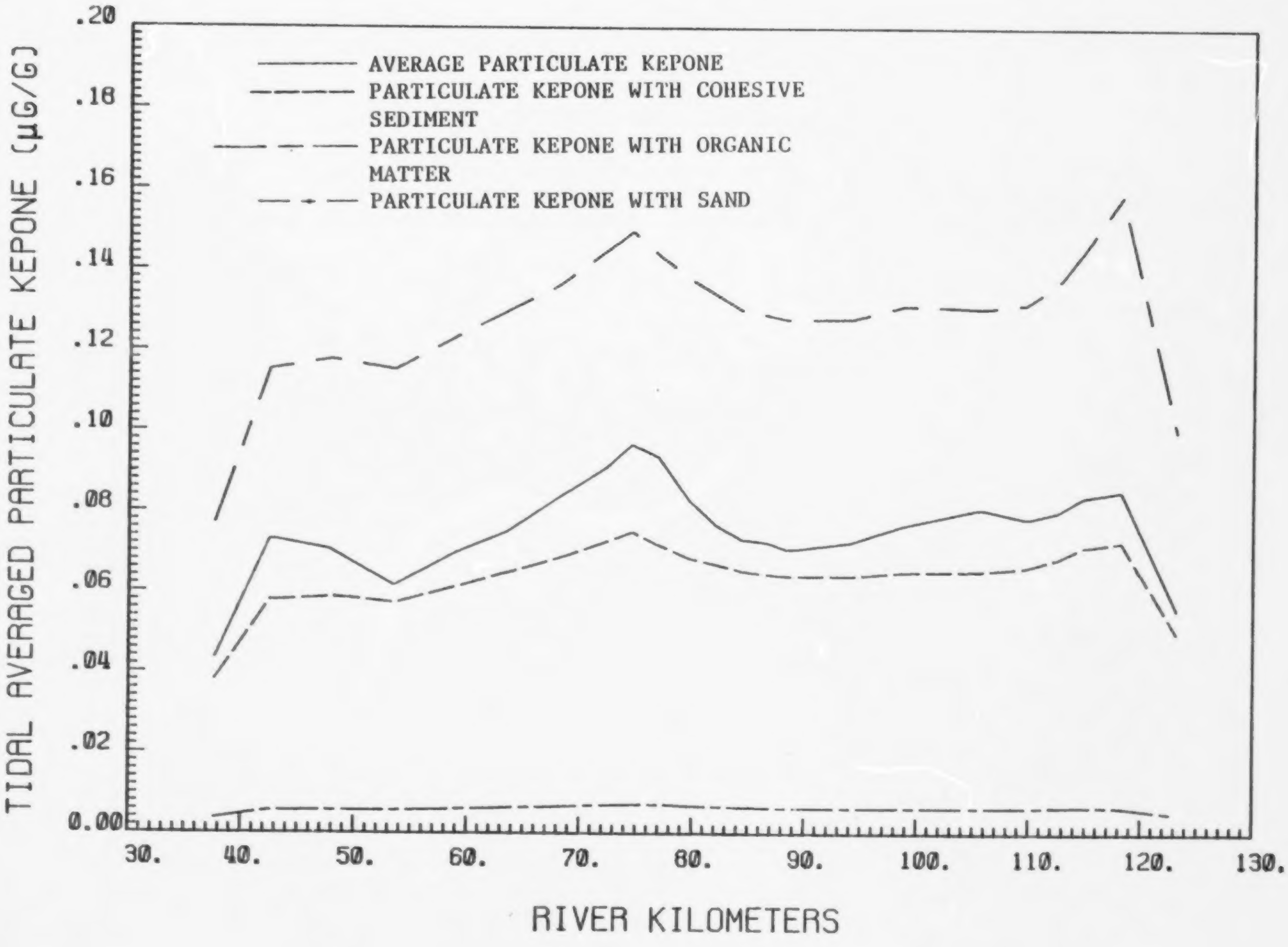

FIGURE M.67. Tidal Averaged Particulate Kepone Concentrations for the Fresh-water Discharge of 681 m^3/sec

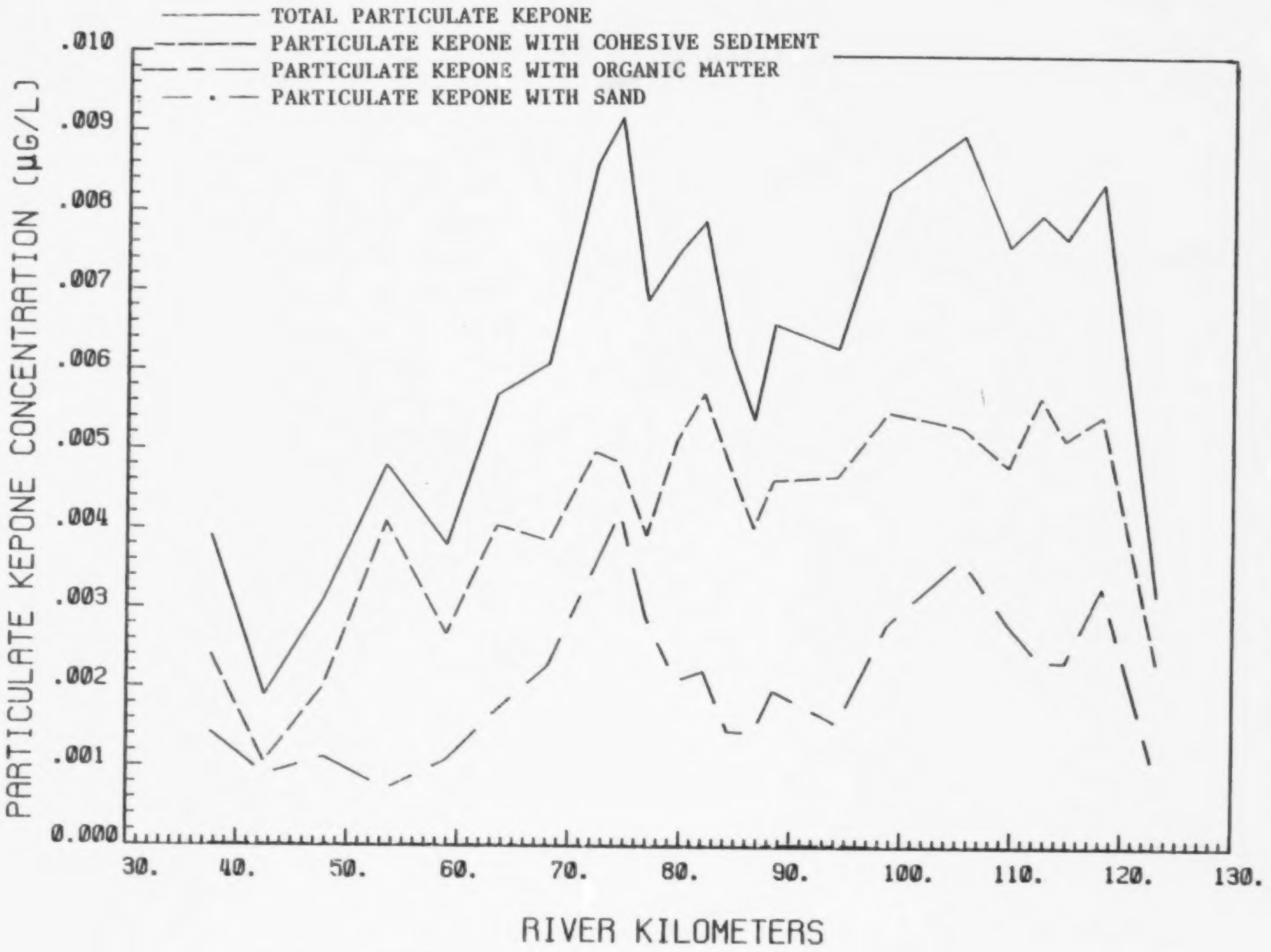

FIGURE M.68. Longitudinal Distributions of Particulate Kepone Concentrations per Unit Volume of Water at Maximum Ebb Tide for the Fresh-water Discharge of 681 m^3/sec

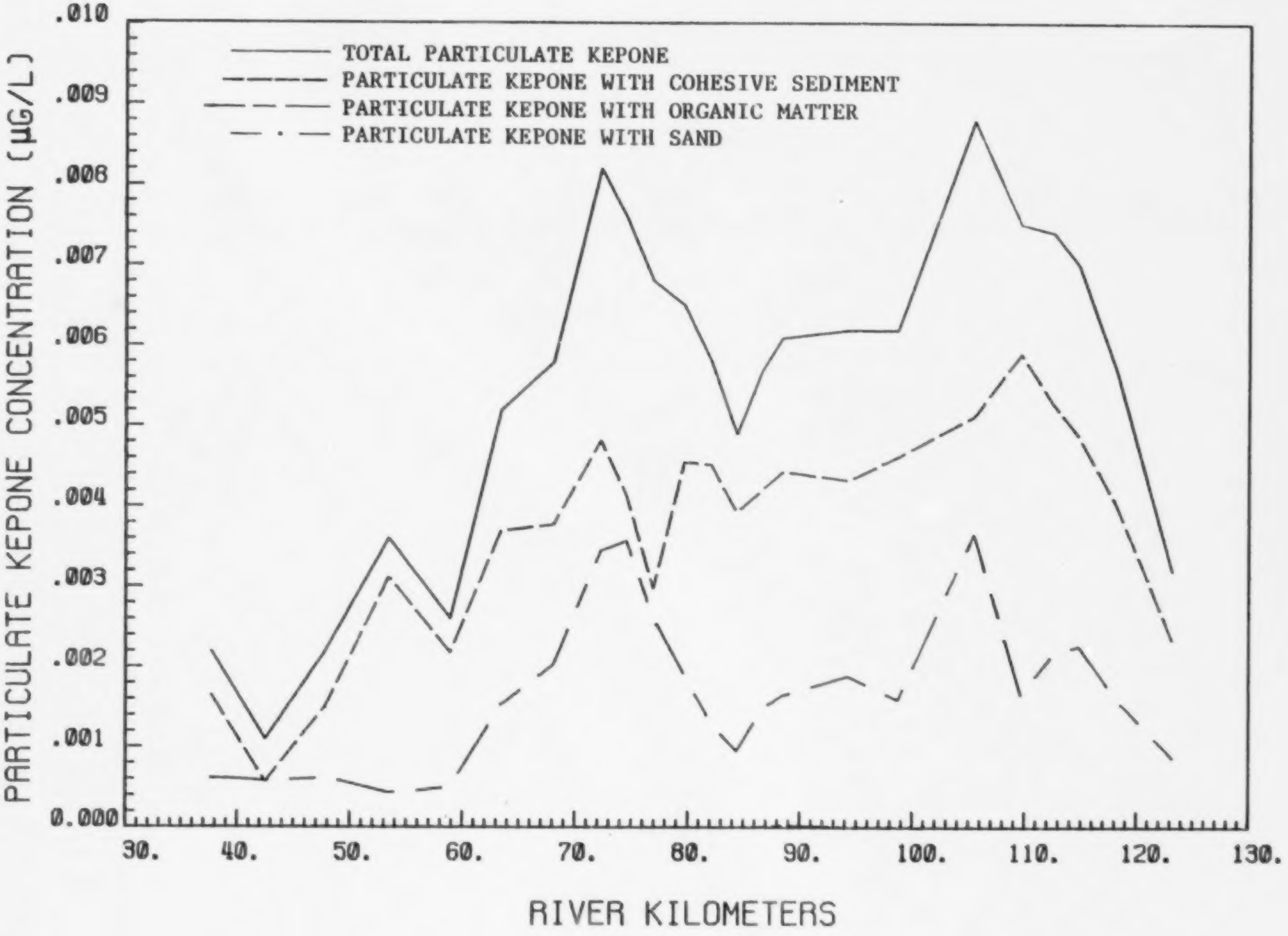

FIGURE M.69. Longitudinal Distributions of Particulate Kepone Concentrations per Unit Volume of Water at Slack Tide for the Fresh-water Discharge of 681 m^3/sec

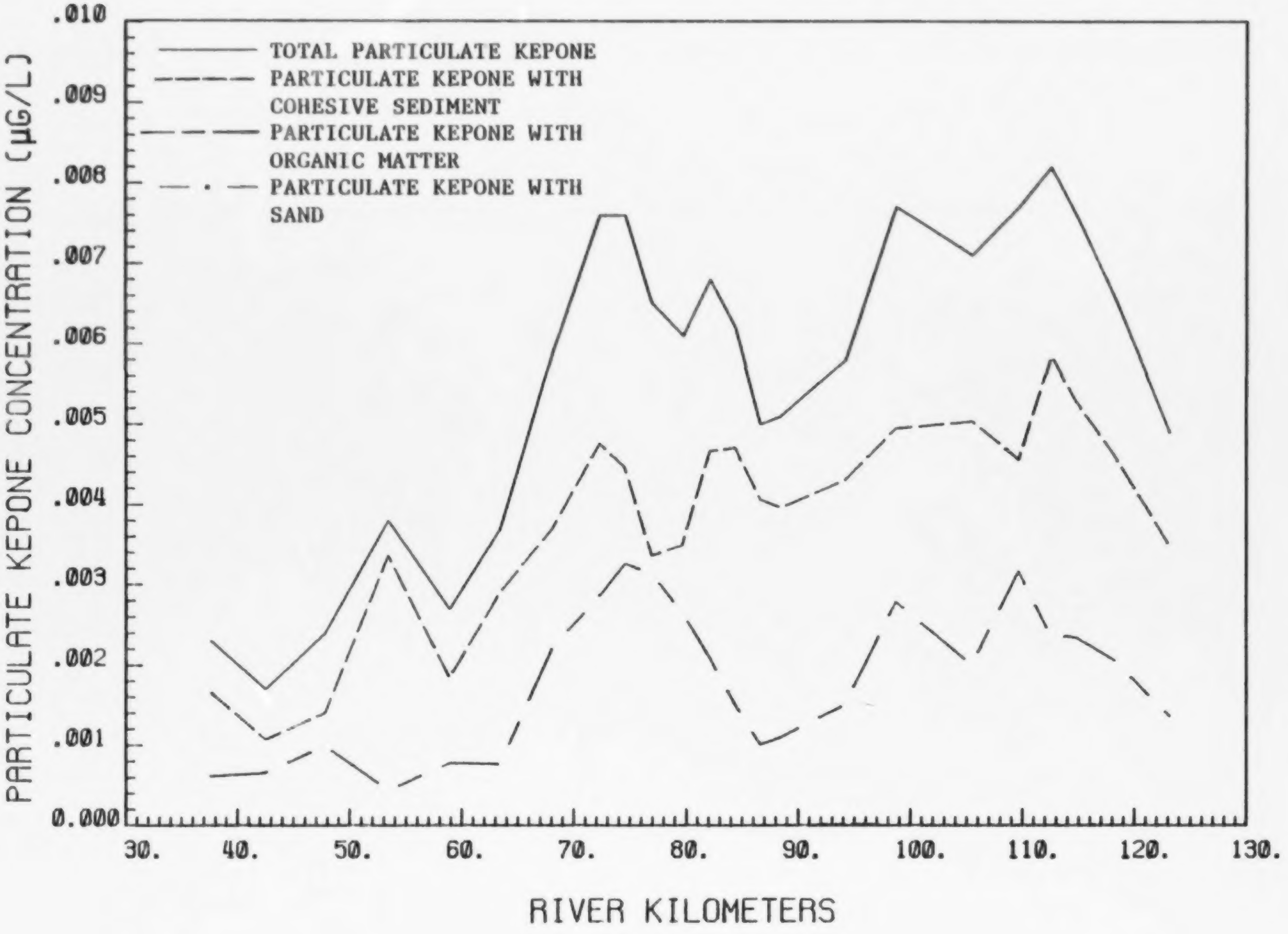

FIGURE M.70. Longitudinal Distributions of Particulate Kepone Concentrations per Unit Volume of Water at Maximum Flood Tide for the Fresh-water Discharge of 681 m^3/sec

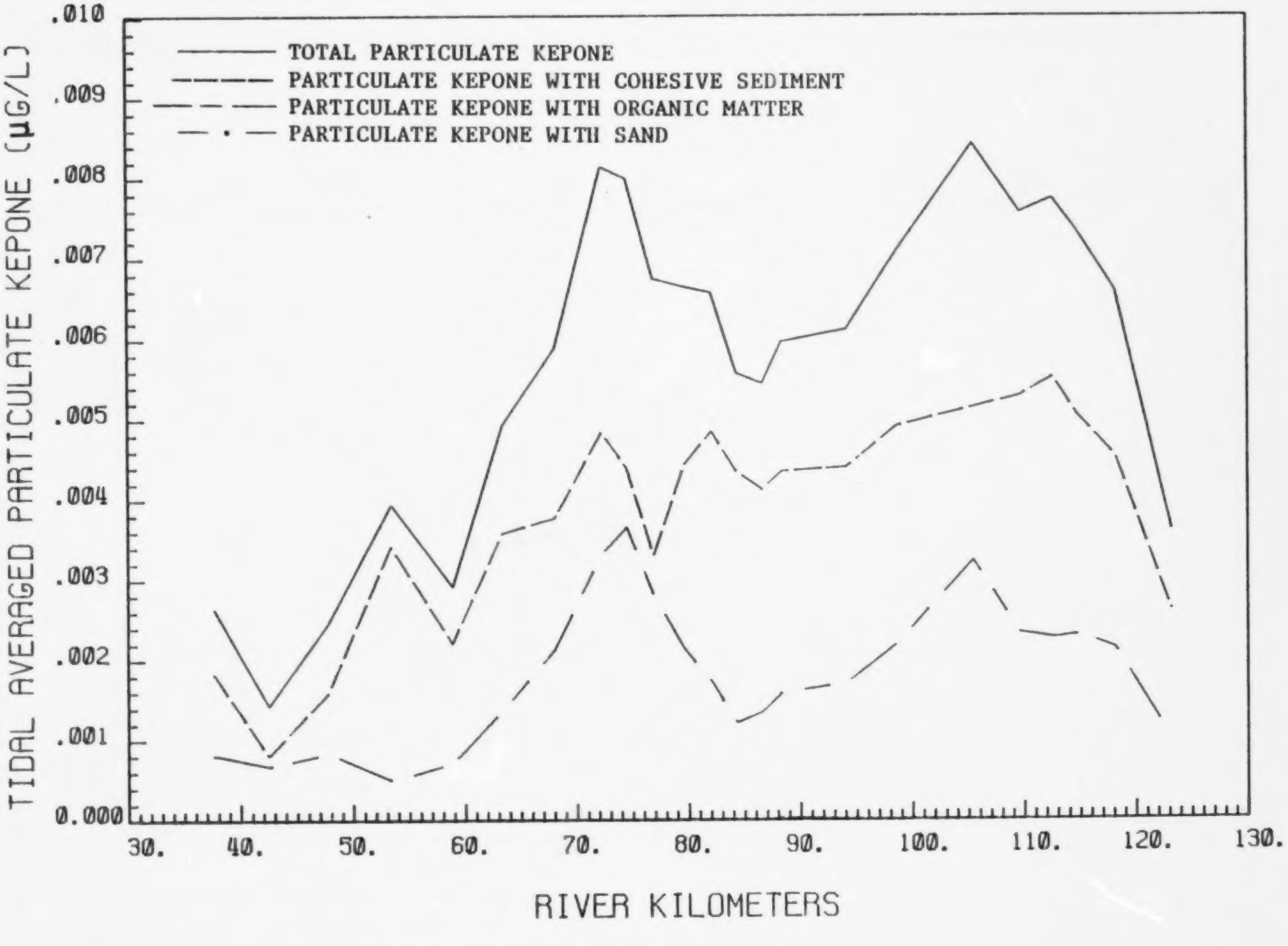

FIGURE M.71. Longitudinal Distributions of Tidal Averaged Particulate Kepone Concentrations per Unit Volume of Water for the Fresh-water Discharge of 681 m^3/sec

Figures M.72 through M.75 present longitudinal distributions of dissolved, particulate and total Kepone concentrations. As shown in Figure M.75, tidal averaged total Kepone concentration varies from 0.0072 μg/ℓ to 0.0155 μg/ℓ with an average value of 0.0124 μg/ℓ. Tidal averaged particulate Kepone concentration obtained over the entire 86-km reach is 0.00575 μg/ℓ which corresponds to 46% of the total Kepone concentration. Similarly overall dissolved Kepone concentration is 0.00665 μg/ℓ which is 54% of the total Kepone concentration. As compared to Cases 1 and 2, particulate Kepone for this case has the highest contribution to the total Kepone, due to the higher rate of bed scouring and subsequent sediment concentration under these flow conditions.

The simulation results also reveal that at Burwell Bay, the tidal averaged concentrations of total particulate and dissolved Kepone are 0.0093 μg/ℓ, 0.0026 μg/ℓ, and 0.0066 μg/ℓ, respectively. Hence, it is estimated that under this net fresh-water discharge of 681 m^3/sec, approximately 200 kg of Kepone per year is flushed out from the tidal James River toward Chesapeake Bay. Of that total, 28% or 56.0 kg is being transported by sediment and 72% or 144 kg is moved out in a dissolved form.

Changes in accumulated river bed elevation and in Kepone concentration on the river bed surface are shown in Figure M.76 and M.77. Unlike Cases 1 and 2, an overall net erosion of the river bed occurs at a rate of 4.1 mm/yr under this high flow condition.

Case 4 - Overall Evaluation Through Combination of Results on Cases 1, 2 and 3

In order to obtain a realistic estimate of Kepone transport, the computer results obtained for Cases 1, 2, and 3 were combined with their frequency of occurrence. As mentioned before, net fresh-water discharges of 58.3 m^3/sec (Case 1) and 681 m^3/sec (Case 3) correspond to the 10 and 90 percentile of discharge. The discharge of 247 m^3/sec (Case 2) is the annual average discharge. To best estimate probable annual Kepone transport, based on the results of these three cases, Case 1, 2, and 3 were assigned to occur 30, 40, and 30% of the time.

Annual total sediment concentration over the entire 86-km study reach is estimated to be 59.0 mg/ℓ. The annual total Kepone concentration over the area is 0.0108 μg/ℓ. The annual particulate Kepone concentration over the area is computed to be 0.072 μg/g or 0.0028 μg/ℓ, while dissolved Kepone concentration is 0.0064 μg/ℓ. Hence, 26% of the total Kepone is transported with sediment and 74% is in a dissolved form.

Similarly, the average annual net bed deposition rate for the 86-km tidal James River reach is estimated to be 0.7 mm/yr which agrees reasonably well with field data obtained during the last 70 years (Nichols, 1972). This also confirms the general validity of the present mathematical simulation.

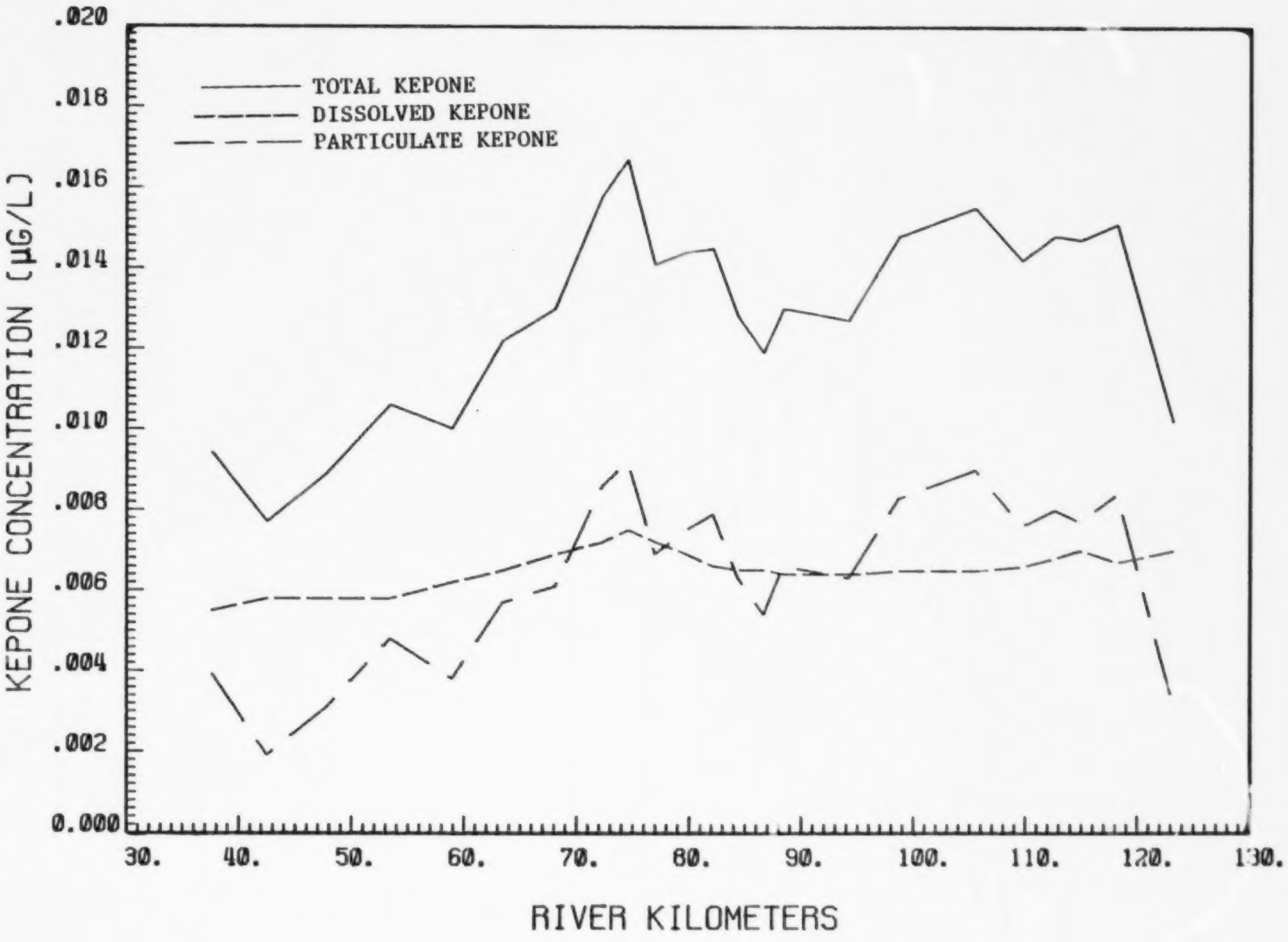

FIGURE M.72. Longitudinal Distributions of Total, Dissolved and Particulate Kepone Concentrations at Maximum Ebb Tide for the Fresh-water Discharge of 681 m^3/sec

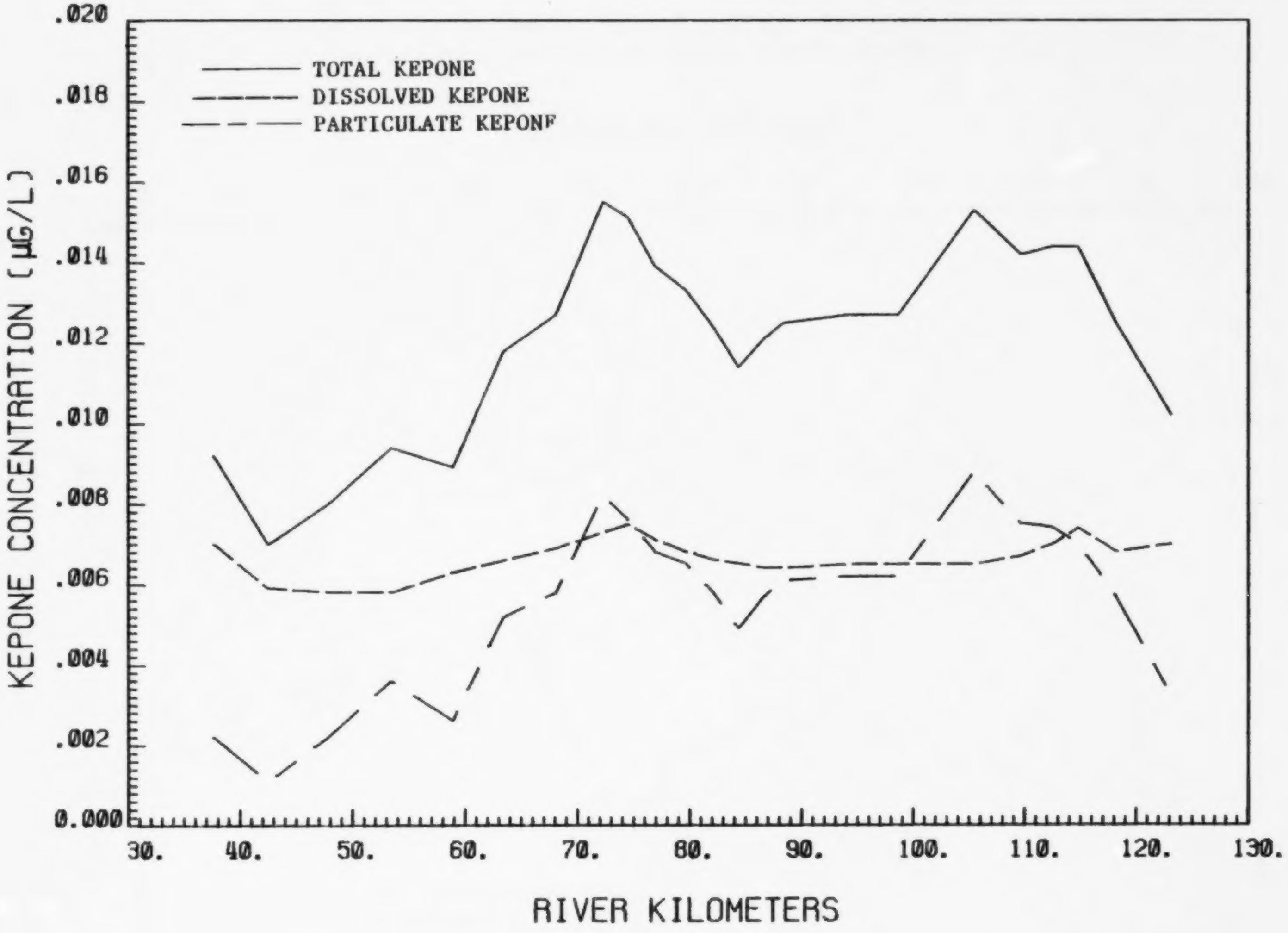

FIGURE M.73. Longitudinal Distributions of Total, Dissolved and Particulate Kepone Concentrations at Slack Tide for the Fresh-water Discharge of 681 m^3/sec

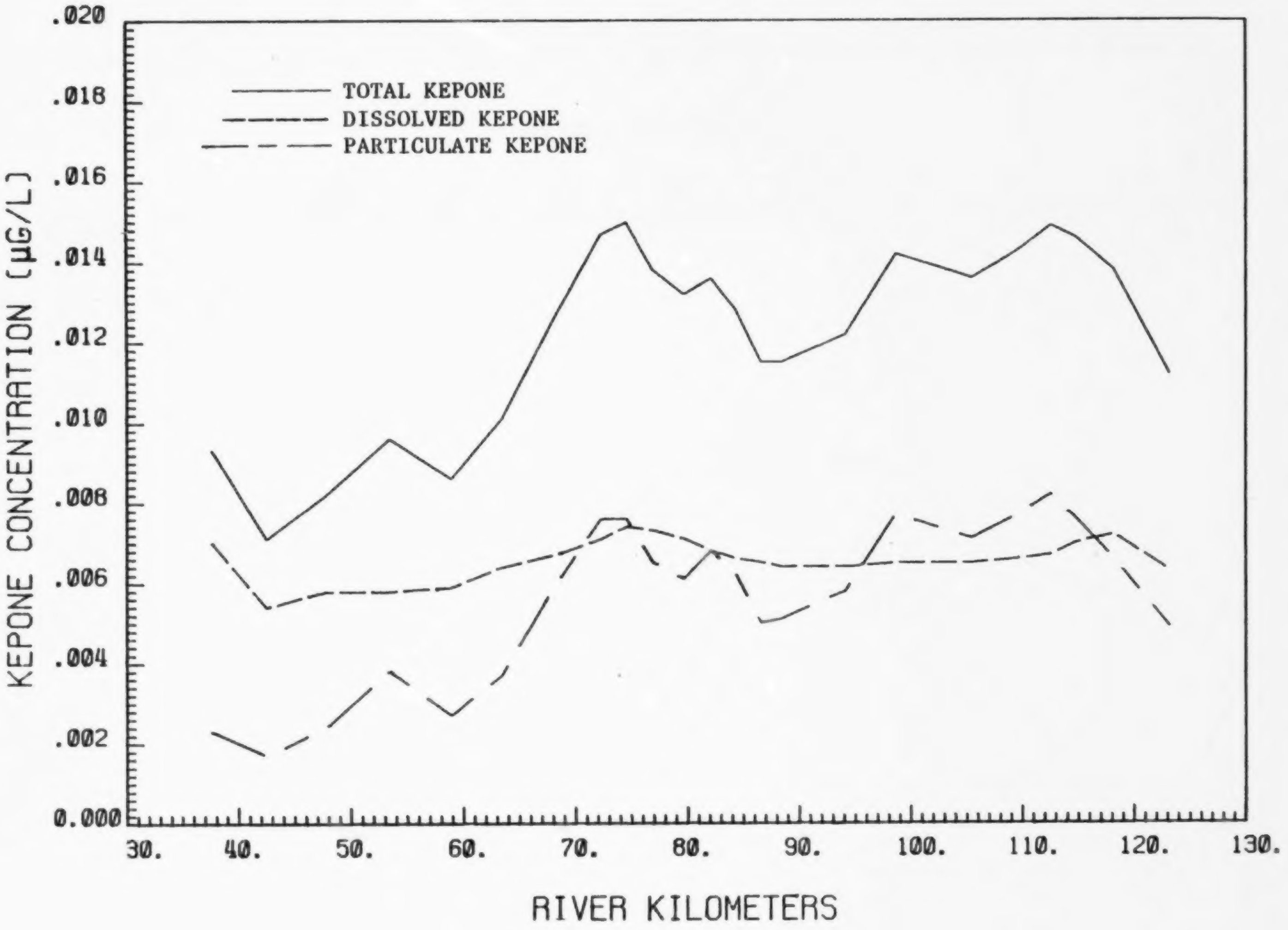

FIGURE M.74. Longitudinal Distributions of Total, Dissolved and Particulate Kepone Concentrations at Maximum Flood Tide for the Fresh-water Discharge of 681 m^3/sec

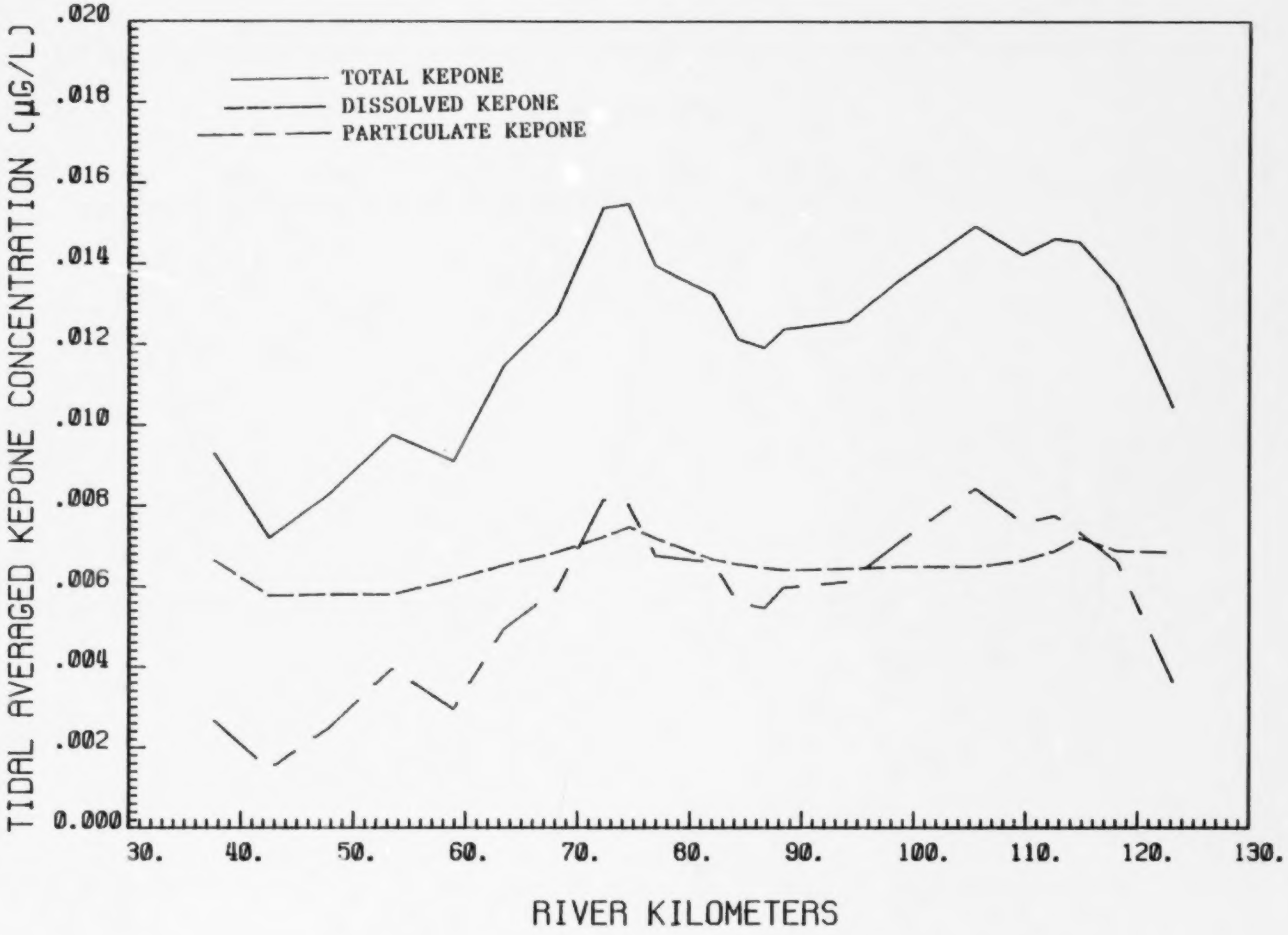

FIGURE M.75. Longitudinal Distributions of Tidal Averaged Total, Dissolved and Particulate Kepone Concentrations for the Fresh-water Discharge of 681 m^3/sec

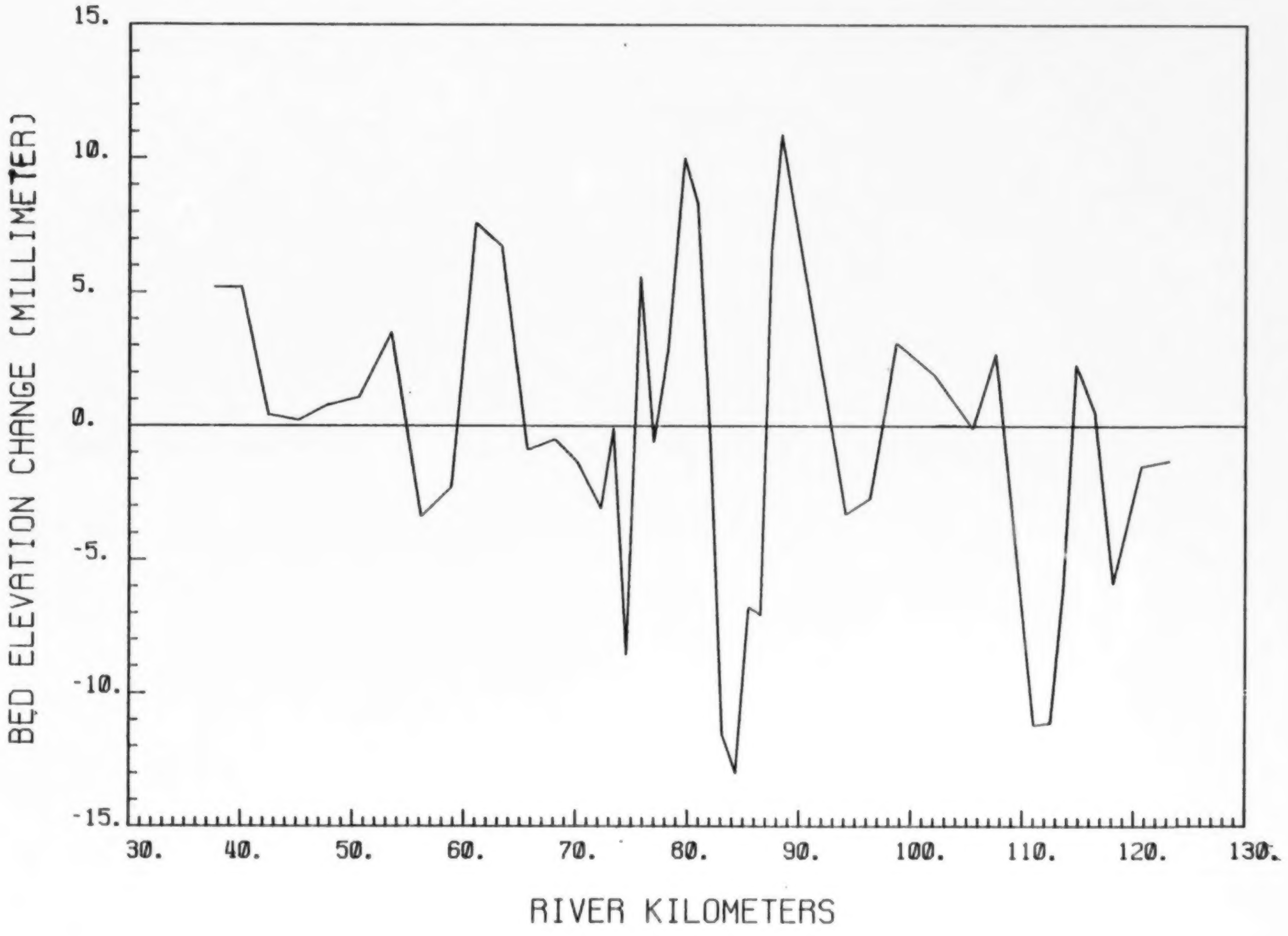

FIGURE M.76. Variation of River Bed Elevation Changes Due to Sediment Deposition and/or Bed Scouring at Maximum Ebb Tide for the Fresh-water Discharge of 681 m^3/sec

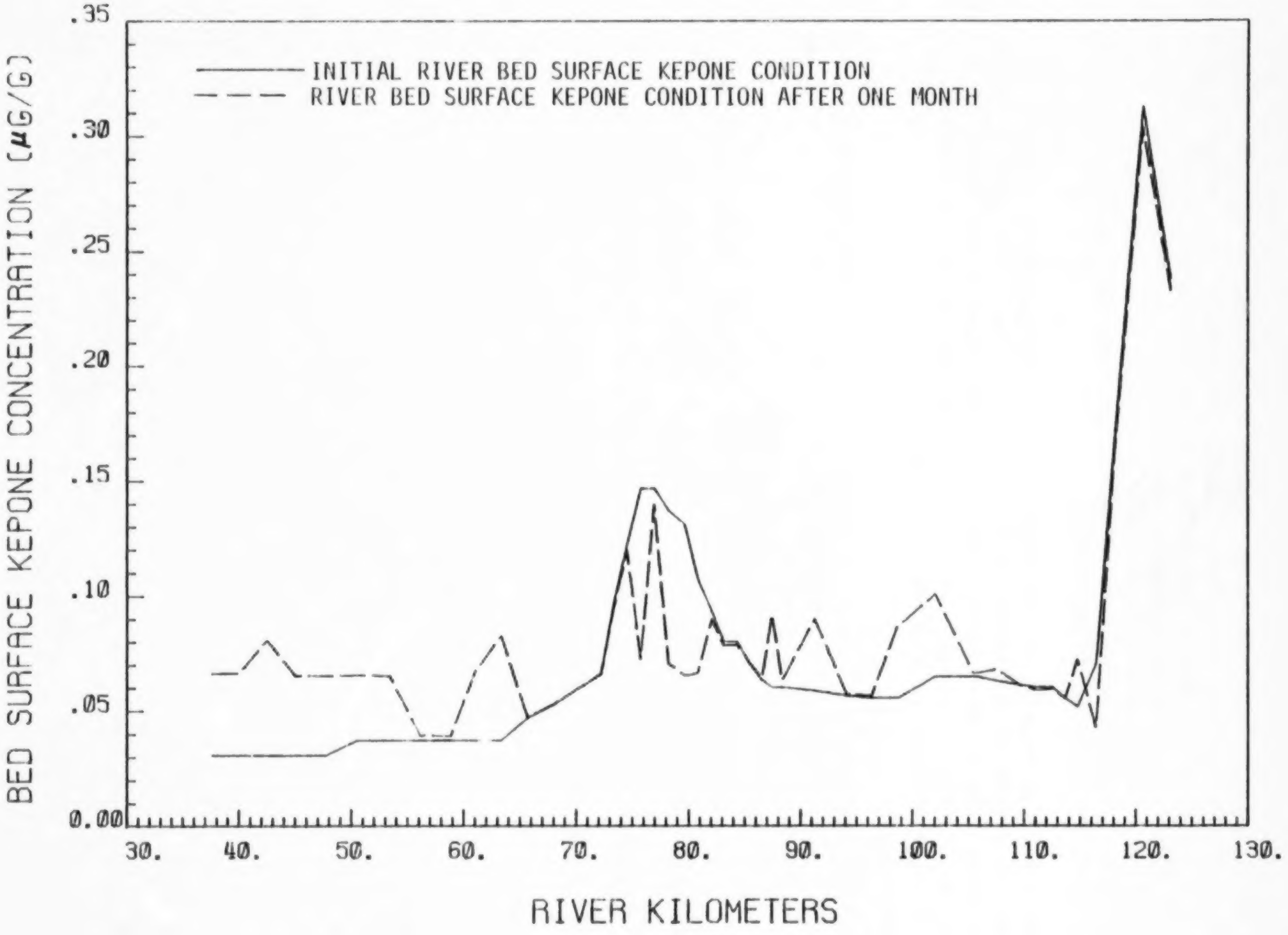

FIGURE M.77. Change in Bed Surface Kepone Concentration Occurred During 1-Month Simulation for the Fresh-water Discharge of 681 m^3/sec

Finally, it is estimated that 89.1 kg of Kepone per year is transported from the tidal James River towards Chesapeake Bay. Of that, 22.5 kg of Kepone is a particulate form associated with sediment, and 66.6 kg is in a dissolved form. Since there are some possibilities that the contaminated sediment is deposited and/or dissolved Kepone is adsorbed by cleaner sediment between Burwell Bay and the James River mouth, 89.1 kg/yr is a conservative estimate. However, since 74% of the Kepone is in the dissolved form, it is judged that changes in the total Kepone concentration between Burwell Bay and the river mouth are not very significant. A summary of simulation results on Kepone migration from Burwell Bay toward Chesapeake Bay and Atlantic Ocean for all four cases is shown in Table M.2.

As mentioned in Chapter V (see Table V.26), approximately 9,600 kg (20,000 lb) of Kepone is estimated to be present in the James River. Hence with a flushing rate of 89.1 kg/yr Kepone from the James River toward Chesapeake Bay and Atlantic Ocean, it may take 108 to 214 yr for natural water-sediment flushing mechanism alone to cleanse the river.

TABLE M.2. SUMMARY OF SIMULATION RESULTS ON KEPONE MIGRATION FROM BURWELL BAY SEAWARD FOR ALL FOUR CASES

	Case 1	Case 2	Case 3	Case 4
Net Fresh-water Discharge (m^3/sec)	58.3	247	681	321
Annual Total Kepone Discharge (kg/yr)	14.0	62.3	200	89.1
Dissolved Kepone Percentage (%)	84.3	80.0	72.0	74.7
Particulate Kepone Percentage (%)	15.7	20.0	28.0	25.3

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APPENDIX N

MOLTEN SALT INCINERATION OF KEPONE LADEN RATES

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MOLTEN SALT INCINERATION OF KEPONE LADEN RATES

Kepone-contaminated residues were produced as a result of laboratory work conducted as a part of this study. An available lab-scale molten salt furnace was employed to destroy these wastes. Operations were monitored closely to prevent Kepone release and to evaluate the process as a means for future disposal of Kepone.

A schematic of the experimental apparatus is shown in Figure N.1. The reactor consisted of a 14 in. length of 4 in. Sch 40 Inconel 600 pipe. Sodium carbonate (1700 g-3.7 lb) was added to the reactor to give a 10 cm (4 in.) depth in the molten state. After melting the Na_2CO_3 and attaining a temperature of 900°C, the system was leak-checked prior to proceeding with the experiment.

Activated carbon contaminated with Kepone was added in 5 g (0.01 lb) batches every 15 minutes through a 1.3 cm (1/2 in.) Inconel tube submerged in the molten salt. Submerged additions assure contact of the Kepone with the molten salt. Operations were uninterrupted during carbon addition by using the valved lock chamber shown in Figure N.1. Contaminated charcoal was added to the lock chamber with the lower ball valve closed and with air flow entirely through the line below the lower ball valve. After addition to the lock chamber, the upper ball valve was closed, the lower ball valve opened, and air flow diverted through the upper line to sweep the carbon into the molten salt.

The air flow rate was 2 ℓ/min (0.5 gal/min) for 3 hr of the 3-1/2 hr run. A flow rate of 3.8 ℓ/min (1.0 gal/min) during the remaining time caused plugging of the off-gas lines with molten salt particulates. The superficial linear velocities (SLV), defined as the volumetric flow rate at reactor conditions divided by the empty-reactor-cross-sectional area, at 2 ℓ/min (0.5 gal/min) and 3.8 ℓ/min (1.0 gal/min) were 1.8 cm/sec (0.059 ft/sec) and 3.4 cm/sec (0.11 ft/sec), respectively. Such low velocities should not result in molten salt carryover. Carryover of molten salt and plugging of the off-gas lines was probably caused by moisture in the activated carbon feed. The internal reactor pressure was observed to increase to values ranging from 70 to 350 g/cm^2 (1 psig to 5 psig) with each carbon addition. These pressure surges were undoubtedly the result of moisture flashing to steam at the reactor temperature of 900°C.

Undecomposed Kepone was removed from the off-gas in two activated carbon absorbers in series. Kepone in the activated carbon was eluted for analysis to determine the amount of Kepone undecomposed by exposure to the molten salt. Molten salt samples were also taken from Kepone analysis. Total Kepone-contaminated carbon added during the run was 80 g (0.18 lb) containing 0.135 μg Kepone/g (ppm) or a total of 10.8 μg Kepone. Analyses of samples are given in Table N.1.

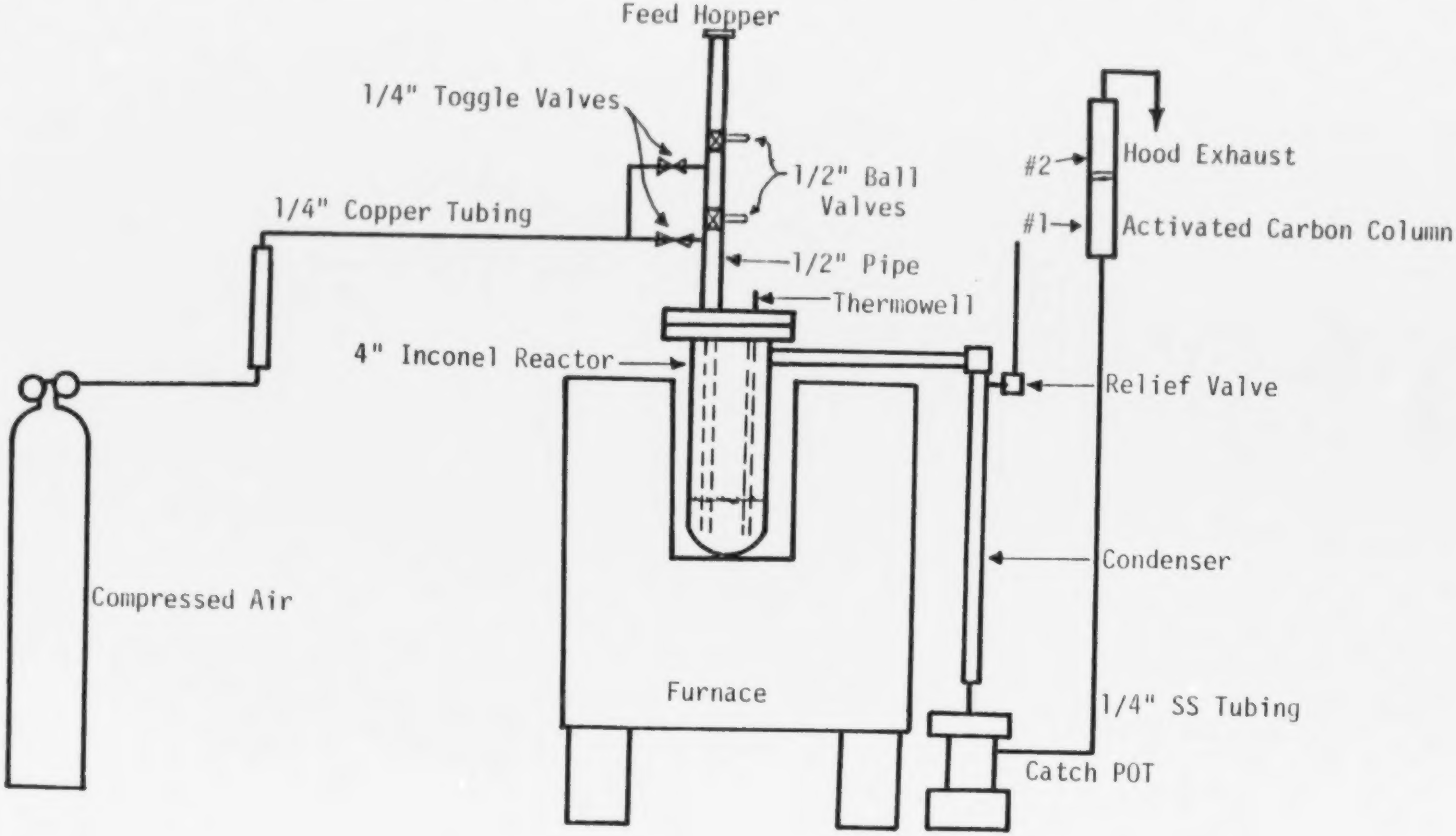
Feed Hopper
1/4" Toggle Valves
1/2" Ball Valves
1/4" Copper Tubing
1/2" Pipe
Thermowell
4" Inconel Reactor
#2
Hood Exhaust
#1
Activated Carbon Column
Relief Valve
Condenser
Compressed Air
Furnace
1/4" SS Tubing
Catch POT

FIGURE N.1. Experimental Apparatus for Molten Salt Incineration Tests

TABLE N.1. ANALYSIS OF SAMPLES FROM KEPONE DESTRUCTION IN MOLTEN Na_2CO_3

Sample	Kepone Concentration μg/g	Total Weight of Kepone μg
Molten Salt at end of run*	0.0033	5.6
Molten Salt after further air purge**	0.007	1.2
Activated Carbon		
Trap #1	<0.002	<0.037
Trap #2	<0.001	<0.019

---

*Sample of molten salt at the end of the run.

**Sample of molten salt after further air purging for 2 hr at 3 ℓ/min air and 900°C.

At the end of the run, considerable unburned carbon remained in the molten salt as did 52% of the Kepone added. Further purging of the molten salt at 3 ℓ/min (0.8 gal/min) air for 2 hr at 900°C reduced the Kepone level to 0.0007 μg/g, (ppm) or 11% of the input Kepone. Of the total Kepone added to the molten salt, less than 0.5% was detected in the activated carbon traps, indicating over 99.5% destruction and retention in the molten salt.

Surprisingly, a large fraction of the Kepone, 11% after complete burning of the carbon, remained in the molten salt. The Kepone shows a remarkable resistance to destruction in the molten salt and apparently does not volatilize significantly since less than the detectable amount was found in the activated carbon traps. Of the Kepone added to salt and not retained by the molten salt (10.8 μg - 1.2 μg = 9.6 μg), less than 0.6% was found in the charcoal traps. No plating on effluent lines walls was detected.

The same apparatus and procedure as used with Na_2CO_3 were used to test the destruction of Kepone in molten $K_2S_2O_7 \cdot K_2SO_4 \cdot V_2O_5$ at 500°C. For the experiment, 1350 g of $K_2S_2O_7$, 225 g of K_2SO_4, and 225 g of V_2O_5 were added to the reactor. Air flow was maintained at 1.5 ℓ/min (0.5 gal/min) corresponding to an SLV of 0.9 cm/sec. Unlike the run with Na_2CO_3, no pressure surge in the reactor was noted when the 5 g additions of Kepone contaminated carbon were added to the molten salt, which indicated a low moisture content in the carbon. A total of 60 g (0.132 lb) of Kepone-contaminated carbon (8.1 μg Kepone) was added during the 4-hr run. Results of sample analysis are shown in Table N.2.

TABLE N.2. ANALYSIS OF SAMPLES FROM KEPONE DESTRUCTION IN MOLTEN $K_2S_2O_7 \cdot K_2SO_4 \cdot V_2O_5$

Sample	Kepone Concentration μg/g	Total Kepone μg
Molten Salt	<0.007	<1.3
Activated Carbon		
Trap #1	<0.0007	<0.013
Trap #2	<0.005	<0.093

Less than detectable concentrations of Kepone were found in all samples. Less than 16% of the Kepone added to the molten salt was found in the molten salt at the end of the run. Complete destruction of the Kepone was probably effected. The Kepone in the first and second carbon traps was <0.2% and <1.1% of the Kepone added, respectively. For some unknown reason, the detection limit was 0.005 μg/g (ppm) for the #2 carbon sample. Actually since the #2 trap follows #1, the Kepone in the #2 carbon should be less than in the #1 carbon. The Kepone is probably completely destroyed in the system, but certainly over 99.6% is destroyed under conditions used in this experiment.